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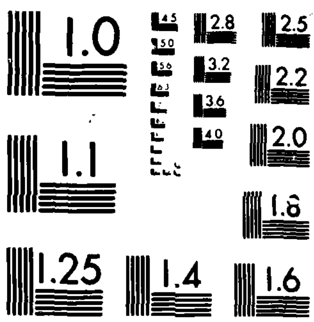

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A KNOWLEDGE BASED SYSTEM FOR THE DESIGN OF MOBILE SUBSCRIBER EQUIPMENT COMMUNICATIONS NETWORKS

THESIS

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THESIS

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Preface

The purpose of this project was to generate interest in the use of expert systems for tactical communications planning. While there currently are in existence several systems that are capable of doing portions of what the design set forth in this project proposed, the intent of this project was to develop an architecture that could combine the various capabilities into one unified system. The fact that at the time this project was started the Army was in the process of acquiring a new generation of communications equipment provided a unique opportunity to target the developed system to the new equipment.

The architecture that is implemented by the prototype system appears to be very promising for further expert system development. While the prototype that was implemented is limited to designing terrain independent networks, I feel that the incorporation of terrain data into the prototype system should be relatively straightforward.

I would like to take this opportunity to thank those whose help was instrumental in the completion of this project. I would like to thank my advisor, Major Seward, for his patience, willingness to listen, and timely advice. The assistance provided by Lieutenant Krieger in coordinating with the Signal Center at Fort Gordon, Georgia and his personal enthusiasm for this project is deeply appreciated. Finally, I wish to thank my wife, Donna. Without her understanding and support, this thesis would never have have been possible.

Brin A. Tolliffe

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Abstract

This project designed a knowledge based system that will assist tactical communications systems planners design tactical communications networks. The system was developed to be used with a new generation of United States Army tactical communications equipment, the Mobile Subscriber Equipment (MSE) System, and was named the Mobile Subscriber Equipment Network Design System (MSENDS).

MSENDS is designed to use terrain knowledge available from digital terrain databases, and knowledge specific to the MSE system to perform the network design process. The heuristic network design method of clustering is used to develop an initial terrain independent network design. The initial design is then evaluated using terrain knowledge and MSE specific knowledge for constraint satisfaction. Network redesign strategies are invoked as unsatisfied constraints are identified. The evaluation and redesign of the network is performed iteratively until a satisfactory design is achieved.

A prototype of MSENDS was implemented to evaluate the proposed design. A blackboard architecture that enabled non-chronological backtracking to be used was implemented. The prototype does not use terrain knowledge in its design or redesign operations; only MSE specific knowledge is used by the prototype.

It was found that the use of the design, evaluate, redesign architecture, coupled with MSE specific knowledge was able to design a network with a lower cost than was produced by a system employing no domain specific knowledge. These results indicate that the proposed system may be useful in the design of tactical communications networks.

I. Introduction

Background

Current Army doctrine requires that continuous and reliable communications be available for effective command and control to be exercised over combat forces throughout the battlefield (9:Chap 3, 15). To meet this requirement, the Communications Electronics Management System (C-EMS) was developed to combine centralized control of communications planning and communications resource allocation with decentralized execution of the communications mission (8:Chap 1, 2). One of the tasks of communications electronics management is communications electronics systems engineering.

Communications electronics systems engineering is a design process in which the organic communications elements of a land based combat force are allocated to those units of the combat force requiring communications support to produce a communications network (7:Chap 6, 1). The goal of communications electronics systems engineering is to provide the best possible communications to the combat force within the constraints imposed by (39:Chap 8, 6):

1. Available communications equipment.
2. Communications doctrine.
3. The terrain over which the combat force is operating.
4. The tactical situation.

Multichannel radio is the primary communications medium for units at division level or higher (7:Chap 4, 3). Multichannel radio is a communications system that is able to provide multiple communications channels simultaneously utilizing radio as the transmission medium (7:Chap 4, 3). For units relying upon multichannel radio, planning of the multichannel radio portion of the communications network is a critical step in the communications electronics systems engineering process. Because the ultimate effectiveness of the radio network rests primarily upon the selection of sites for the individual radio terminals that comprise the network, the site selection process plays an extremely important part in the overall process of producing a communications network.

The selection of locations for the radio terminals can be a very time consuming process. If the communications network is to be designed for an area in which the combat force has operated before, a great deal of the site selection process can be eliminated by choosing locations that have been successfully used in the past. In the more likely event that the combat force will be operating in an unfamiliar area, the site selection process must be fully carried out.

In addition to the constraints under which the communications electronics systems engineering design process must operate to achieve its goal, other factors that may be considered during the site selection process are (7:Chap 4, 2-4):

1. User locations and requirements.
2. Current status of existing networks.
3. Site security required for each of the possible locations.
4. Accessibility of each of the possible sites.
5. Connectivity between each of the possible sites.

6. Need for radio repeaters between each of the possible sites.

7. The ability of the enemy to detect an operational site.

8. The ability of the enemy to impair an operational site.

Site selection is essentially a process of elimination that uses the above listed factors and constraints to reduce the possible locations from literally every location within the combat force's area of operation to those that appear to have the highest probability of being used successfully. For a combat force in a deployed situation, the site selection process becomes a repetitive process that begins before the combat force deploys, and must constantly be performed throughout the duration of the combat force's deployment (unless the situation is such that the deployed force neither moves forward nor backward, nor suffers losses of any kind) (11:Chap 6).

The amount of time that must be devoted to the communications electronics systems engineering design process is dependent upon the frequency of displacement of major supported units. Current doctrine has set as objectives a rate of from one to three displacements per day for division level command posts and a rate of from three to five displacements per day for brigade level command posts (11:Chap 6, 4). These high displacement rate objectives imply that a great deal of time must be allocated to the communications electronics systems engineering design process, and a significant portion of that time will be devoted to the site selection process.

One way to minimize the amount of time that communications electronics planning personnel must dedicate to the site selection process is to provide them with a system that can perform the site selection process in the same way a person would. A computer system that is designed to solve a problem using the same knowledge a human would use, with the goal of achieving a solution equal to that of a human, is known as an expert system (2:43-45). Thus, the use of an expert system by communications electronics planning personnel is one possible way to reduce the time spent selecting signal site locations.

Problem Statement

The United States Army is currently in the process of fielding a new generation of tactical communications equipment at the division and corps level. The new equipment, known as Mobile Subscriber Equipment, will be used to provide a grid network of interconnected nodes covering the majority of the area of operation of a corps or division. The communications medium that will be employed between the nodes of the grid is multichannel radio. Units of the combat force requiring communications support will connect to communications switching equipment with wire or cable. The communications switching equipment will in turn be connected to the grid network by means of multichannel radio (36).

The problem of selecting locations at which to site the new tactical multichannel radio communications equipment is a network design problem in which the locations of nodes in the network are given, and the objective is to determine the network topology. This is a constrained version of the general network design problem known as the Topology, Capacity, and Flow Assignment Problem (23:1331). There are no known methods to obtain an exact solution to design problems of this type other than explicit enumeration, however, heuristic methods can provide acceptable solutions (16:55-57). The fact that multichannel radio has been successfully used for many years to support units in both training and combat situations also indicates that there are effective heuristics that have been utilized to provide acceptable solutions to the site selection process. Thus, the goals of this project were:

1. Design an expert system that combines network design heuristics and site selection heuristics for the new communications equipment being introduced by the Army.
2. Validate the expert system design through construction of a prototype site selection system for use at the division level.

Scope

The heuristic methods used for the network design process are based upon the concept of clustering originally set forth by McGregor and Shen (26) and modified by Schneider and Zastrow (32). Heuristic methods used for the site selection process are based upon concepts set forth for the employment of Mobile Subscriber Equipment in (36). Communications planning doctrine established by the United States Army Signal School was also considered.

The prototype expert system implemented was limited to producing terrain independent network designs. This was done to test the design and control architectures that were set forth in the system design in an environment requiring a minimum of user interaction. Testing was accomplished by designing a terrain independent communications network for a set of unit locations generated for a deployed division size force.

The results obtained from the prototype expert system were compared to a network design produced by applying the heuristic method of

Schneider and Zastrow to the same set of unit locations. This second network design was produced without using any of the site selection heuristics available to the prototype system.

Assumptions

Because the Mobile Subscriber Equipment has not yet been purchased by the Army, there is no definitive doctrine for its employment. Thus, it was assumed that current doctrine, as modified by (36), was applicable.

The major assumption that was made regarding the employment of the Mobile Subscriber Equipment during the development of this project was that the elements of each individual grid node would be collocated. Based on the information currently being put forth in the Army Signal School's concept of how the new signal equipment will be employed (36:Chap 4, 14-16), this was a valid assumption.

The impact of the above assumption was that nodes were sited as a single entity to which radio connectivity was established. If this assumption had not been made, each individual radio assemblage assigned to a node would have required a separate location to have been selected for it. This assumption also implied that a single node, with all of its associated equipment, covers several hundred square meters.

Current digital databases deal with terrain areas that have dimensions of 100 meters by 100 meters. Vertical resolution is limited to an accuracy of plus or minus 12.5 meters. It was assumed that this quality of terrain resolution is adequate for the system that was proposed. Based on the reported results of other design efforts utilizing digital terrain databases for radio propagation (28, 40), this assumption has been found to be valid. An increase in database resolution would enhance the ability of the system to perform the site selection process.

Organization

Chapter II presents the background against which this project was developed. In particular, an overview of the Communications Electronics Management System is presented along with a detailed description of the communications electronics systems engineering process. Additionally, an overview of some automated systems that are currently utilized in the network design process is presented, as well as an overview of expert systems and their use in the design process.

Chapter III presents the design concepts for the system proposed by this project. A description of the prototype system that was implemented is presented in Chapter IV. Chapter V presents the results produced by the prototype system and compares them to the results produced by the system implemented using the more general heuristic technique. Conclusions and recommendations for further research are presented in Chapter VI.

II. Background

This chapter contains background material which explains why a system that performs the process of selecting locations at which to place tactical multichannel radio equipment can be useful, and why an expert system approach was chosen. First, a broad overview of the Communications Electronics Management System (C-EMS) and the process followed in the design of a tactical multichannel communications network is presented. The purpose of this presentation is to show how the site selection process affects each of the C-EMS functional elements and the network design process. This is followed by a presentation of some automated systems that are used for terrain analysis. The purpose of presenting these systems is to provide insight into the type of information that is available from analysis of terrain data. Finally, an overview of both expert systems and the process of design is presented at a very general level, and the reason for choosing an expert system approach to the site selection process is discussed.

Communications Electronics Management System

As stated previously, the Communications Electronics Management System (C-EMS) was developed to combine centralized control of communications planning and communications resource allocation with decentralized execution of the communications mission (8:Chap 1, 2). Within a theater of operations, each level of command has organic communications electronics management elements which are responsible for integrating the communications assets of that level into the overall communications system within a particular theater of operations while providing the communications needed to support that level's combat mission (8:Chap 4, 1).

There are three basic levels of command within a theater of operations: the theater army (also known as echelons above corps (EAC)), the corps, and the division (8:Chap 4). Four functional C-EMS elements are organic to each of these levels: a Communications System Planning/Engineering Element (CSPE), a Communications System Control Element (CSCE), Communications Nodal Control Elements (CNCE), and Communications Equipment Support Elements (CESE) (38:1).

Communications Equipment Support Element (CESE). The CESE is the functional element of the C-EMS. Each of the individual equipment assemblages of a communications electronics (C-E) system is considered a CESE. As the lowest functional element in the C-EMS, the primary function of CESE personnel is to operate the equipment of which the communications system is composed in response to the directions of the the next higher functional element, the CNCE (8:Chap 7, 1). Additional CESE functions include monitoring communications links and equipment for outages or degradations and performing tests on system circuits or equipment at the direction of the CNCE (8:Chap 7, 6-7).

As the functional C-EMS element, a CESE is primarily affected by the site selection process at an operational level. A CESE will be directed to a site location selected by higher elements in the C-EMS. A CESE does not generally participate in the site selection at a planning level.

Communications Nodal Control Element (CNCE). The lowest C-EMS control element is the CNCE which has responsibility for management and technical control of subordinate CESE's. The management functions of the CNCE include coordinating communications requirements, establishing circuit and system testing, maintaining records and reports, and initiating restoration or rerouting of circuits or systems if required. The technical control functions of the CNCE include circuit conditioning, monitoring systems and circuits to maintain system standards, recording test results reported by subordinate CESE's, and maintaining system and circuit status records (8:Chap 7, 2-7).

The CNCE plays an active role in the site selection process as the functional element with management responsibility for the CESE. Reconnaissance information provided by the CNCE must be considered when the final site selection is made. The CNCE will also analyze user locations and user requirements to determine where CESE extensions will be placed. Until the CNCE accepts proposed site locations, the network design cannot be considered complete (8:Chap 6, 3).

Communications System Control Element (CSCE). The CSCE at each command echelon is the direction center for the communications system installed at that level. The primary responsibility of the CSCE is to prepare the system installation orders that implement CSPE planning and engineering decisions and direct the actions of subordinate CNCEs. Other responsibilities include maintaining and analyzing system status information received from subordinate CNCEs, assuring effective system operation through implementation of traffic control measures, allocating communications resources to maintain an effective communications system, and reporting the status of the communications system to the commander (8:Chap 7, 1-2).

The role of the CSCE in the site selection process is to provide coordination between the CNCEs and CSPE. This includes providing accurate information to the CSPE regarding equipment and system status, coordinating reconnaissance efforts by the CNCEs, providing results of reconnaissance efforts to the CSPE, and reviewing the network layout developed by the CSPE. The CSCE also establishes support responsibilities for the CNCEs and provides assistance to the CNCEs as required (8:Chap 6, 3,17).

Communications System Planning/Engineering Element (CSPE). The CSPE is the highest functional level of the C-EMS, responsible for long range planning and detailed engineering (8:Chap 2, 5). The planning and engineering functions are followed in a logical progression that culminates with the issuing of C-E orders directing system installation, operation, and maintenance. Planning functions performed by the CSPE include developing C-E plans that support the mission of the combat force, preparing contingency plans to support frequent displacement of command posts, allocating frequencies to minimize electromagnetic interference, and allocating communications resources to satisfy communications requirements of the supported combat force (8:Chap 5, 1-18).

The primary engineering function of the CSPE is to prepare the communications network layout. Other engineering functions include allocating resources and routing traffic to handle anticipated voice and data traffic flow within the network, analyzing system performance data provided by lower management elements, and coordinating electronic counter-countermeasures. The selection of sites for the CESEs that will ensure efficient user service and enable nodal connectivity to be established is a primary consideration of the CSPE while preparing the communications network layout. The sites selected must enable system connectivity to be established while also providing acceptable levels of service to users. With the input provided by lower elements of the C-EMS, the CSPE makes the final decision for the locations of the functional elements based on site suitability and network engineering requirements (8:Chap 6).

Tactical Communications Electronics Systems Engineering

Multichannel communications systems are the primary means of providing communications service to the supported elements of a combat force (7:Chap 4, 3). The design of the multichannel communications network is the responsibility of the CSPE at each level of command (8:Chap 6).

A multichannel communications system is capable of simultaneously providing more than one communications channel over a single transmission path. Radio, cable, or wire may be used as transmission medium in a multichannel system. Radio is used more frequently than wire or cable since systems using radio can be installed for use over greater distances in less time than can systems using wire or cable (7:Chap 4,3).

The goal of the C-E systems engineering process is to use the available communications resources to provide a communications system that meets the communications requirements of the supported unit with a high grade of service and low message delay times (8:Chap 6, 1). To accomplish this goal, a ten phase development process that follows

"...certain logical procedures that rest on standard principles of communications use," (37:Chap 5, 35) can be used. The ten phases of this procedure are (37:Chap 5, 35):

1. Determine the mission of the combat force.
2. Compile and evaluate communications requirements of supported elements of the combat force.
3. Determine what communications resources are available to provide the required support.
4. Develop an initial network configuration based upon support requirements.
5. Adjust network configuration based upon site selection criteria and support requirements.
6. Develop network routing plans.
7. Allocate subscriber services.
8. Establish procedures for C-EMS reporting and control functions.
9. Issue communications-electronics orders implementing the network.
10. Test the installed network.

Of the ten phases presented above, the two phases most likely to result in a CSPE concluding that the signal unit it is organic to is unable to meet a supported unit's communications requirements are the resource assessment phase and the network adjustment phase. Because each signal unit assigned to support a combat force is organized with equipment and personnel specified by tables of organization and equipment that reflect current doctrine, attempting to justify a need for additional equipment can be expected to be difficult (10:Chap 2, 7). Therefore, every effort must be made to meet the communications requirements by adjusting factors within the control of the signal unit and the supported force. This is best accomplished by adjusting the the locations of the CESEs within the communications network or the locations of units supported by CESEs to enable a viable network to be configured.

From the information presented above, it can be seen that each level of the C-EMS is involved in or affected by the site selection process. Furthermore, the selection of sites for CESEs and supported units is the best method, within the constraints of the tactical communications electronics system engineering process, that a CSPE at a particular command level can use to provide supported units doctrinal communications support with the amount of communications equipment a signal unit is authorized. Thus, automation of the site selection process may enable a communications unit to provide better support by enabling more network configurations to be evaluated in order to find a configuration that best satisfies the communications requirements of the supported unit within the constraints imposed by terrain and equipment.

Existing Terrain Analysis Systems

Terrain analysis is a process in which the geographic features of a given land area are evaluated to determine their effect on a particular course of action (6:279). Geographic features may be identified by conducting a physical reconnaissance of the actual land area or by reviewing a representation of the land area, such as a map, photographs, or a digital terrain database.

A digital terrain database is data, stored in a computer, that represents a physical land area by means of partitioning the total area into small cells and assigning digital values to the geographic and descriptive components of each cell. The geographical components most commonly represented are location and elevation. Descriptive components identify items of interest within the domain of the course of action for which the terrain is being evaluated (1:78-79).

Two methods are generally utilized for storing the information that has been recorded for each cell. The first method records all descriptive and geographic information about an individual cell in one or more words of computer memory, utilizing bit fields to encode the recorded data (40:44). The second method creates separate entries for each piece of descriptive and geographic data that pertain to each individual cell. The separate entries are then stored in either separate data files for each category of recorded information or as entries to some form of a database management system (1:80-81).

No matter which storage method is used, some means of indexing the individual cells within the database must be devised. The most common method of indexing cells within a digital terrain database uses the location of the cell to generate an index key. Geographic coordinate systems, such as the Universal Transverse Mercator (UTM) system and the Universal Polar Stereographic (UPS) Grid system, superimpose an orthogonal coordinate system on geographic projections, enabling cells to be indexed within the database by their row and column location in the grid system (18:9). In addition to providing a method by which to index the individual cells of the land area, both the UTM and UPS systems enable linear horizontal measurements and interpolations to be made (12:Chap 3, 7-14).

Several terrain analysis systems have been documented in recent literature. Many systems have been designed to predict radio frequency propagation characteristics over a given land area. Other systems have been designed to analyze terrain features to aid personnel engaged in tactical planning or environmental planning and control.

Propagation Prediction Systems. Radio propagation prediction systems that use digital databases for terrain analysis have been reported by researchers in Canada (40), Japan (28), Germany (24), Italy (5), France (27), and the United States (17, 14). Although the specific format of the terrain databases used by each of these systems is generally different, the same basic types of information are used to accomplish one or more of three basic functions.

The three basic functions that propagation prediction systems may be used for are: simulation of a transmission station to predict its area of coverage and effects on other stations, determination of parameters for communications system design, and production of predicted values for comparison with measured values to enable improvements to be made to the prediction system's database and propagation model (1:77-79). The three types of propagation predictions that are most useful for simulation and design purposes are: point to point propagation predictions, single radial predictions from a specified point, and predictions of area coverage from a specified point (40:47).

The three types of propagation predictions are made from a specified transmitter location called the base station. The data that must be known about the base station is its location, the height and radiation pattern of its transmitting antenna, and the strength and frequency of its transmitted signal (1:77-78). The result from any of these three prediction types will be a predicted value for either the field strength, signal strength, path loss, or signal to noise ratio for a particular point or area (40:47).

For both point to point and single radial propagation predictions from a base station, the location of the receiving station must be specified as a single point within the resolution limits of the database. In addition to the receiver location, the height of the receiving station's antenna must also be provided for point to point predictions. Varying the height of either the transmitting or receiving antenna or varying the base station's transmission frequency will change the point to point propagation prediction produced. For single radial predictions, varying the distance of the receiving station from the transmitting station will change the prediction result (40:47).

The area coverage prediction method uses the azimuth of each of the boundaries of the area for which coverage prediction is desired (or a starting azimuth and an angle of coverage) and the maximum distance from the base station for which the coverage is to be predicted rather than using data for a single specified receiver location as the point to point and single radial prediction methods do (40:47). The results of an area prediction can be either areas in which the factor predicted has a constant value (27:75), or contour lines that reflect constant predicted values for the desired factor (1:78).

For each cell contained in the database used by a propagation prediction system, two items of geographic data, location and elevation, must be included as part of the digital terrain representation. Other information that may be able to provide correction factors to propagation predictions, and is therefore in the domain of interest of the prediction process, may be included as descriptive components for each cell in the database (1:78).

Terrain information that has been included as descriptive components for cells in the databases of the propagation systems referenced above consists of a description of the predominant type of ground cover for each cell. The Canadian system allows for seven types of ground cover: tree cover, bare ground, fresh water, sea water, marsh, suburban, and high density urban (40:44). The German system reduced the descriptions to four: urban areas, forests, open areas and water (24:55). The other systems provide similar descriptions, and each system uses the descriptive information to make propagation prediction corrections based on radio signal attenuation for the various types of ground cover described.

<u>Other Terrain Analysis Systems</u>. Two systems that perform terrain analysis using a digital terrain database have been developed for purposes other than radio frequency propagation predictions. One of the systems was developed for tactical planning purposes and analyzes terrain to determine its effect on cross country mobility and the visibility of points or areas from a specified location (35). The other system performs terrain analysis to aid in predicting the environmental impact of activities conducted on the Fort Hood Military Reservation (18).

Both the tactical planning system and the environmental planning system contain the same two pieces of geographic information, location and elevation, for each cell as do the propagation systems. However, the descriptive portions of these systems contain a much greater amount of information. The difference in the amount of information required is due to the fact that the propagation prediction systems are used for relatively specialized tasks while the tasks of the tactical and environmental planning systems are much more general.

The descriptive components included in the tactical planning system are slope, vegetation, soil, urban areas, roads, railroads, waterways, water bodies, and obstacles, (35:3). The environmental planning system has twenty-eight categories of descriptive data, including such things as noise contours, endangered species ranges, archaeological and historical sites, military training areas, and protected archaeological areas, as well as vegetation, soil, slope, streams, and other similar descriptive items (18:35).

The large amount of descriptive data included in the tactical planning system enables it to perform a much wider range of analysis than the propagation prediction systems. For example, the intervisibility operations of the tactical planning system provide terrain profile models for optical or electronic visibility, target acquisition models that can predict where a target will become visible to an observer at a specified location, and masked area models that depict what areas are obscured from the view of an observer at a specified location and height above ground level. Intervisibility operations in the radio frequency range are also possible, enabling the system to produce much of the information available from the more specialized propagation prediction systems. The mobility tasks of the system can predict areas in which various types of vehicles may or may not be able to travel, provide information as to the amount of protection afforded by terrain features from hostile fire, predict the amount of aerial concealment provided by vegetation in a given area, and provide information for use in planning river crossing operations (35:4-9).

Rather than analyzing terrain and terrain features for their effect on human undertakings, the environmental planning system is designed to serve as an aid to planners who are interested in the effect of human undertakings on the terrain and terrain features in the area of operations. To achieve this purpose, one of the two functions of the environmental planning system enables environmental planners to specify an area and determine if certain individual features or combinations of features exist within that area. In this way, by knowing what actions were planned in the given area, the person requesting the terrain data can predict what the effects of the action will be (18:9-11).

The second function enables planners to specify individual features or combinations of features and locate areas that contain the desired features. This function allows a planner who knows the activity being performed to choose an area in which the effects can be predicted. For the environmental planning system, the large amount of descriptive data enables much more detailed requests to be handled in less time than a manual system would be able to accomplish (18:9-11).

From the information presented above, it can be seen that a wide range of information is currently able to be represented by means of a digital terrain database. Current applications are varied and research into more applications is ongoing. The limiting factor for any application using digital terrain information is the resolution of the terrain features that are represented in the database. Thus, terrain analysis systems are currently able to provide information useful for planning purposes, but are not currently able to eliminate the requirement for ground reconnaissance when terrain features become decision factors.

Expert Systems and the Process of Design

Expert Systems. Computer programs that solve problems and perform tasks requiring the specialized knowledge and degree of experience that, if possessed by a human would qualify that person as an expert, are known as expert systems (29:284). Expert system design is currently one of the most commercially successful areas of the field of Artificial Intelligence, with systems functioning at the expert level in such disciplines as mineral prospecting, computer systems configuration, organic chemistry, and medical diagnosis (20:5-6).

Expert systems are generally composed of three parts: a database containing the specialized domain knowledge, a set of rules that reflect the problem solving or task specific knowledge that an expert gains through experience, and a control structure, or inference mechanism, that applies the rules to the data until the problem is solved or the task completed (4:5). The specialized domain knowledge is obtained from sources such as textbooks or reference material and contains symbolic representations of domain objects, concepts, and relationships. The rules that represent an expert's experience are obtained from consultations with human experts and are generally encoded in conditional statements of the form: IF condition THEN action (30:4-5). The control structure, or inference mechanism, provides the strategy that the expert system uses to apply the rules to the data in order to achieve a solution or complete the task (4:9).

Two general methods for the storage of domain knowledge within an expert system are in common use. The first, known as the private-line method, passes information between proceeses within an expert system. Only the information that a called process may need is passed to it by the calling process, and only the calling and called processes see the information being passed. The second, known as the blackboard method, stores information in an area accessible to all processes within an expert system. Variations on the blackboard method include the reserved spot method, in which processes look for information in specific locations on the global blackboard structure, and the method of interest groups, in which related groups of processes within an expert system look for information in specific regions of the global blackboard (41:141-142).

There are many problem solving paradigms that may be incorporated into the control structure of an expert system. Such paradigms include the generate and test paradigm, constraint propagation, the search of a solution space, and means-ends analysis (41:159). Expert systems that use the generate and test paradigm have processes that generate possible problem solutions and processes that evaluate the possible solutions for acceptability (41:160-164). Constraint propagation is a paradigm in which low level restrictions are used to eliminate higher level choices from consideration (41:45-86). Searches of a solution space proceed through a set of inherently ordered choices to find a solution. Various types of search techniques include exhaustive searches, depth first searches, breadth first searches, and branch and bound searches (41:87-132). Expert systems that use means-end analysis apply processes to a problem in an attempt to reduce differences between the current state of the problem and the desired solution state (41:146-156).

The control structure of an expert system determines how the processes of that system will be used in support of the selected problem solving paradigm. Three common control choices are action-centered control, object-centered control, and request-centered control. In an expert system that uses action-centered control, each process within the system knows which other processes to call to perform desired actions. In a system that uses object-centered control, the descriptions of the objects within the system contain the information required for each object to know how to deal with other objects. A system that uses request-centered control has processes that know what actions they perform and respond to requests for action from other processes (41:135-137).

Areas in which expert systems are best used are those in which there is a large body of specialized domain knowledge, no known algorithmic method to solve the desired problem or accomplish the desired task, and there exist human experts who have had demonstrated success with problems or tasks in the domain (30:3). General categories of problems and tasks that expert systems appear particularly well suited to address are: interpretation, prediction, diagnosis, design, planning, monitoring, debugging, repair, instruction and control (20:14).

The Design Task. Design involves specifying how some object or system is to be created in order to meet a given set of specifications or constraints (34:84). Three classes of design may be identified. The first class of design entails a high degree of innovation and is best characterized by the act of invention. The second class of design involves less innovation than the first and is characterized by tasks such as redesigning an existing item to perform the task it was originally designed for under different conditions than those for which it was initially designed. The third class of design requires the least innovation of the three classes, and is characterized by such tasks as making modifications to an existing item that are within the item's original design constraints (3:174).

For most design problems, a process of top down decomposition is used to reduce the overall design problem to successively lower levels of component design problems (33:187-194). For each level of the decomposition, and as the levels are integrated to form the desired end product, three basic types of decisions must be made: planning decisions, technical decisions, and acceptability decisions (13:634).

Planning decisions involve such choices as: in what order will the tasks identified by the decomposition be accomplished, what resources will be allocated to a particular level of decomposition, and to what testing or analysis will the results of a level of decomposition be subjected. Technical decisions are concerned with choosing the best material to manufacture an object from or selecting the best components with which to create a system. Acceptability decisions involve deciding whether or not the results at each level of decomposition meet specifications established for that level, and whether or not integration of the various levels of decomposition will meet specifications for the end product (13:634).

The design task can be viewed as an iterative process that begins at the lowest levels of decomposition and is repeated as components designed at lower levels are combined at higher levels, ending when the top level design problem is solved. Each iteration of this process involves making technical and acceptability decisions specified by planning decisions made as the design process progresses. Technical decisions generate an initial design for the the level under consideration. Acceptability decisions then determine whether or not the initial design meets the specifications and constraints that planning decisions direct will apply at that level of decomposition. If the initial design is determined to be unacceptable, the design process for that level must be repeated until an acceptable design is found. When an acceptable design is found, it is passed on for use in the design process at the next higher level of decomposition (13:636).

The design process is an ill structured problem with an inherently large solution space (33:187-189). The manner in which the top level problem is decomposed and design decisions made at lower levels of decomposition will affect the top level design solution. The design of lower level components may create unexpected design constraints as they are combined at higher levels requiring that either the components be redesigned to different specifications at the lower level, or that higher level specifications or constraints be changed. It is also possible that several solutions satisfying top level specifications and constraints may become apparent as the design process progresses, requiring that some method for determining which is the best of the possible solutions be established (13:635-636).

Use of an Expert System for Network Design

Using the criteria presented above, it can be seen that the problem of designing a tactical communications network is a problem for which the use of an expert system is appropriate. First, from the information presented in the discussion of tactical communications electronics systems engineering above, it can be seen that a large amount of domain specific knowledge must be available to system designers to meet communications system requirements within the constraints imposed by equipment and terrain. Second, the topological network design problem has no known algorithmic solution (16:55-57). Finally, the design of tactical communications systems has been practiced for enough time to produce people who can be considered experts in the field.

In addition to the fact that the network design problem is one that is appropriate for the development of an expert system, the decision by the Army to acquire new communications equipment (22, 36) provides an opportunity to introduce new technology into the management system that can provide planning and guidance for the use of the new equipment. The new equipment that is being procured is known as Mobile Subscriber Equipment (MSE) and is described in Appendix A.

Thus, since the tactical communications network design problem is a problem for which the development of an expert system is appropriate, and since the acquisition of the new communications equipment provides an opportunity to introduce additional new technology, the decision to design an expert system to aid in the solution of the tactical communications network design problem was made. Specialized domain knowledge for the system will consist primarily of terrain information and equipment information. The terrain information that will be used by the expert system will be of the type that is available from digital terrain databases, as described above. Equipment information will be based on the descriptions of the Mobile Subscriber Equipment presented in Appendix A. The rule base for the system will be developed from guidelines presented in Army Signal Center documents.

III. Design Concepts

A proposed design for an expert system to be used in the development of communications networks for the United States Army's Mobile Subscriber Equipment (MSE) communications system is presented in the following pages. First, an overview of what the proposed system--known as the Mobile Subscriber Equipment Network Design System (MSENDS)--will accomplish, the types of constraints within which MSENDS will operate, and the strategies to be used by MSENDS is presented. This is followed by a discussion of the architecture of MSENDS. Finally, the control structure used by MSENDS is presented.

System Overview, Constraints and Strategies

MSENDS Top Level. A hierarchical decomposition of the proposed Mobile Subscriber Equipment Network Design System (MSENDS) is presented in Figures 1 through 10. At the top level of the decomposition (Figure 1), the output of MSENDS is a proposed communications network. The network is designed to provide communications for the subordinate units of a combat force operating in a geographic area with known terrain features and supported by organic communications elements equipped with known amounts of MSE system equipment.

The network proposed by MSENDS is composed of a set of locations for those items of MSE system equipment that make up the backbone communications network (node centrals) and provide static subscriber access to the backbone communications network (extension switches) as well as the multi-channel radio equipment and super-high frequency radio sets that provide the communications links between the node centrals and

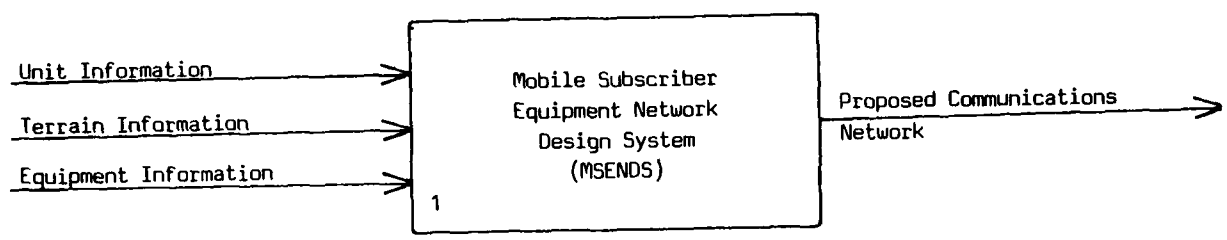


Figure 1. MSENDS Top Level (Block 1)

extension switches. Items of MSE system equipment that provide access to the communications network for mobile subscribers are not dealt with by MSENDS. A description of the Mobile Subscriber Equipment (MSE) system is presented in Appendix A.

The unit information that the user provides to MSENDS must include the identification and composition of the combat force and the identification and composition of the communications elements organic to the combat force. The unit information must also include an identification for each subordinate unit of the combat force requiring communications support, the location of each of the subordinate units, the number of terminals each subordinate unit possesses that require access to the communications network, and the communications priority of each of the subordinate units.

Terrain information that MSENDS requires must be provided in the form of digital terrain databases containing information about the land cover, slope, elevation, cross country movement, and road network for the geographic area in which the supported combat force is operating or expecting to operate. The format of these databases is described in (18), and a general discussion of the use of digital terrain databases for terrain analysis was presented in Chapter II.

Finally, MSENDS requires information about each type of MSE system equipment. This information must include the characteristics of each item of equipment and the number of individual items of equipment possessed by the communications elements providing support to the combat force.

MSENDS Actions. The next level of decomposition (Figure 2), shows the four basic actions performed by MSENDS. First, MSENDS acquires the

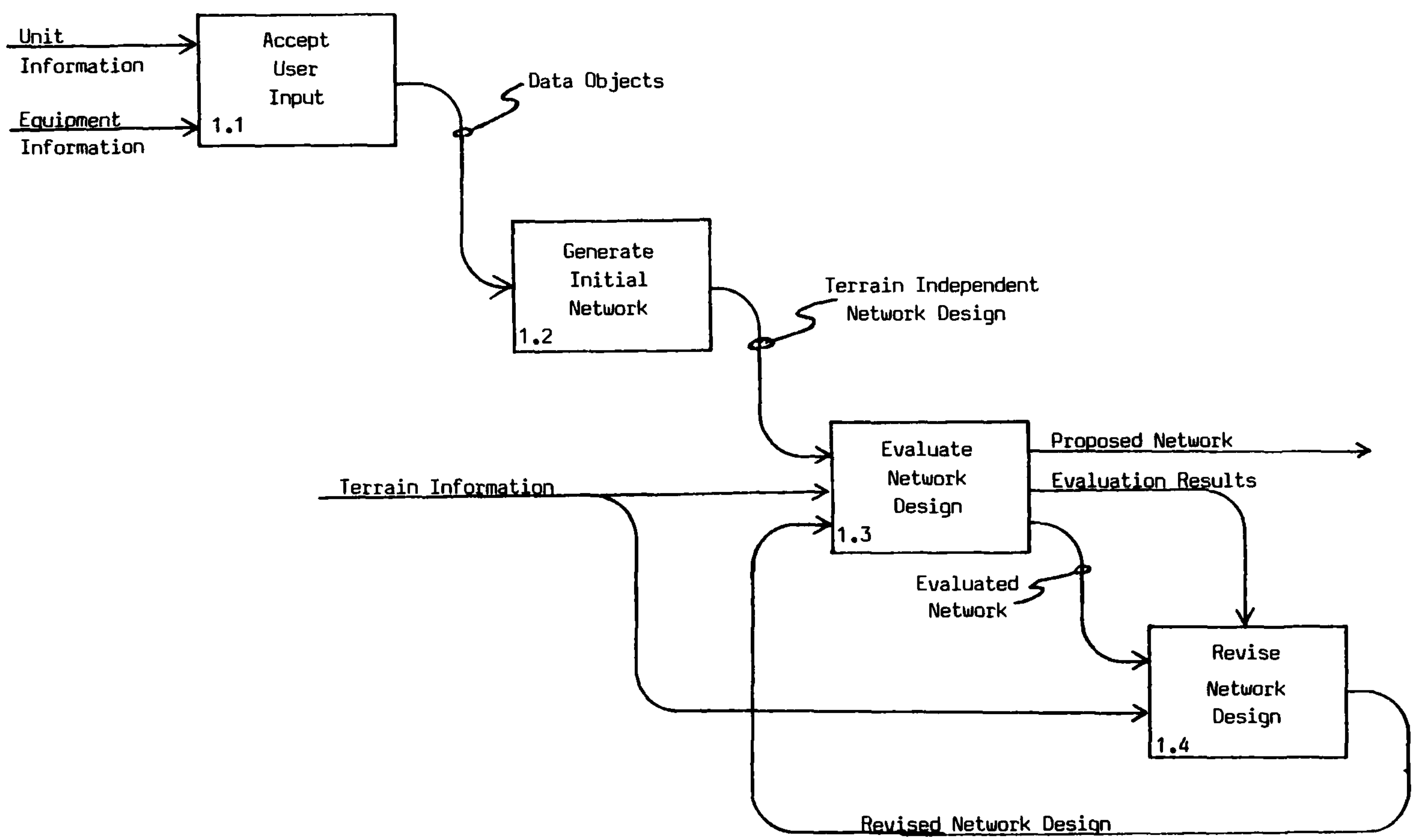


Figure 2. MSENDS Actions (Decomposition of Block 1)

unit and equipment information described above and creates the data objects used throughout the system to represent the units and equipment that make up the communications network (block 1.1). Second, MSENDS generates an initial network design, independent of terrain considerations (block 1.2). The third and fourth system actions, network evaluation (block 1.3) and design revision (block 1.4), are performed iteratively until either a network design that can be proposed by MSENDS is found, or the user terminates the design session.

Initial Network Design. The action of generating a terrain independent network design (block 1.2) can be decomposed into three steps (Figure 3). First, extension switch locations are selected to provide support to subordinate units based upon the communications priority assigned to the unit by the user (block 1.2.1). Next, node central locations are selected to enable each of the extension switches to establish connectivity with at least one node central (block 1.2.2). Finally, the terrain independent network design is completed by establishing connectivity between each node central and not less than two, nor more than four, other node centrals to form a communications network backbone (block 1.2.3).

Heuristic methods are used to select locations for extension switches and node centrals in the terrain independent network design phase of MSENDS. The heuristic method used to select extension switch locations requires that each switch be collocated with the unit having the highest communications priority of all the units served by that switch. If two or more units have equal communications priority, the heuristic method allows them both to be served by one extension switch

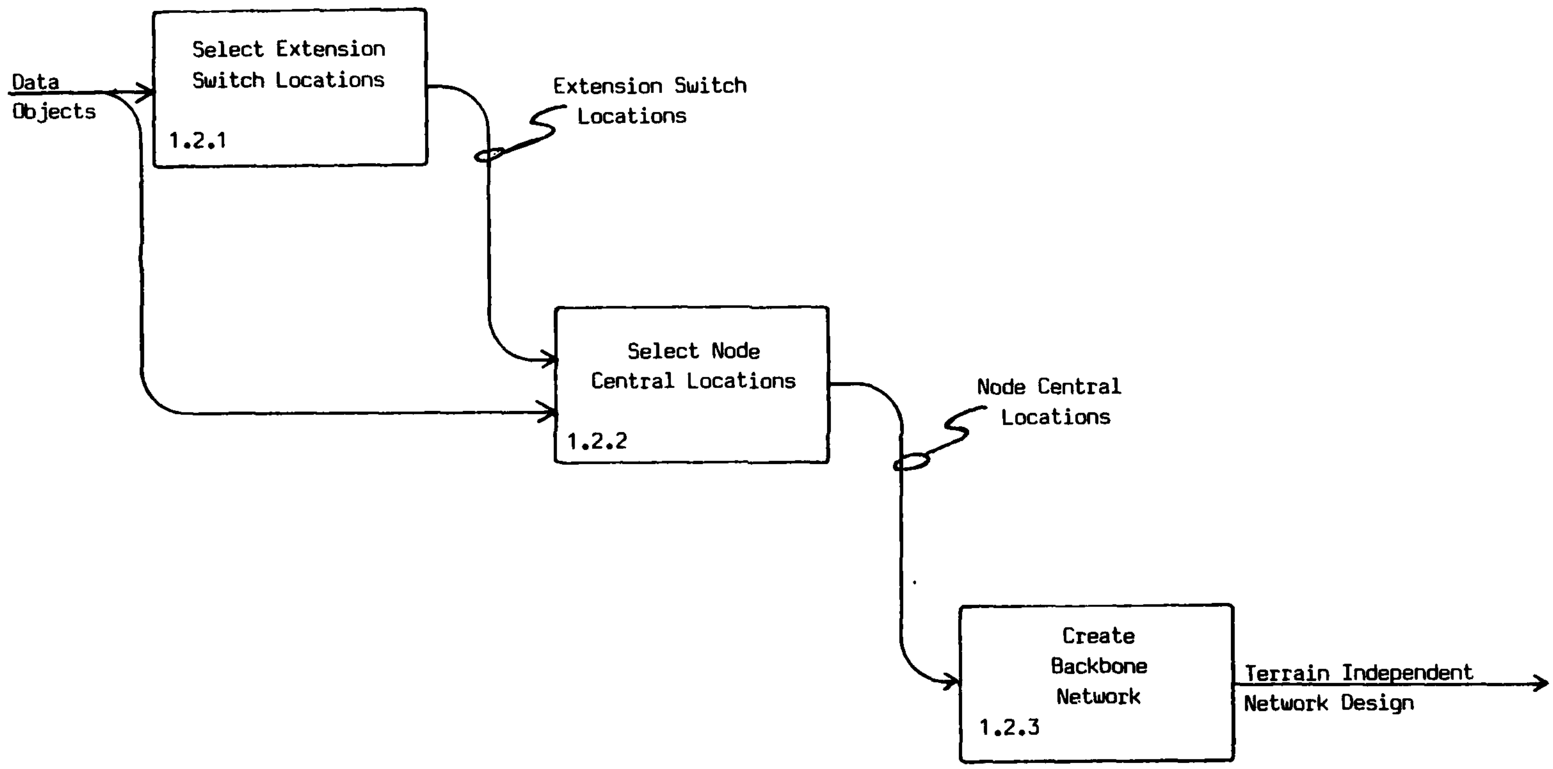


Figure 3. Initial Network Design (Decomposition of Block 1.2)

if the units are either collocated with each other, or can be served by a junction box extended from the switch.

The heuristic method used to select node central locations requires that the distance between a node central and the extension switches that are connected to it be no greater than the planning radius of the MSE line of sight multi-channel radio equipment. Similarly, the heuristic method used in creating the backbone communications network requires that connected node centrals be no farther apart than the MSE multi-channel radio equipment planning radius.

Network Evaluation. Following generation of the terrain independent communications network design, the next action performed by MSENDS is to evaluate the network design for constraint satisfaction. The evaluation of a network design is performed in three phases (Figure 4). First, the location of each of the extension switches in the network is evaluated for terrain and relative location constraint satisfaction (block 1.3.1). If all extension switch constraints are satisfied, the backbone communications network is evaluated next (block 1.3.2). Backbone network evaluation consists of evaluating each node central location for terrain and connectivity constraint satisfaction. Finally, if all backbone communications network constraints are satisfied, the connectivity between node centrals and extension switches is evaluated (block 1.3.3).

During each phase of the evaluation process, as soon as a situation is identified in which constraint satisfaction is not achieved, an appropriate network redesign strategy is invoked to revise the network design being evaluated (Figure 5). Thus, the backbone communications network is evaluated for constraint satisfaction only after all

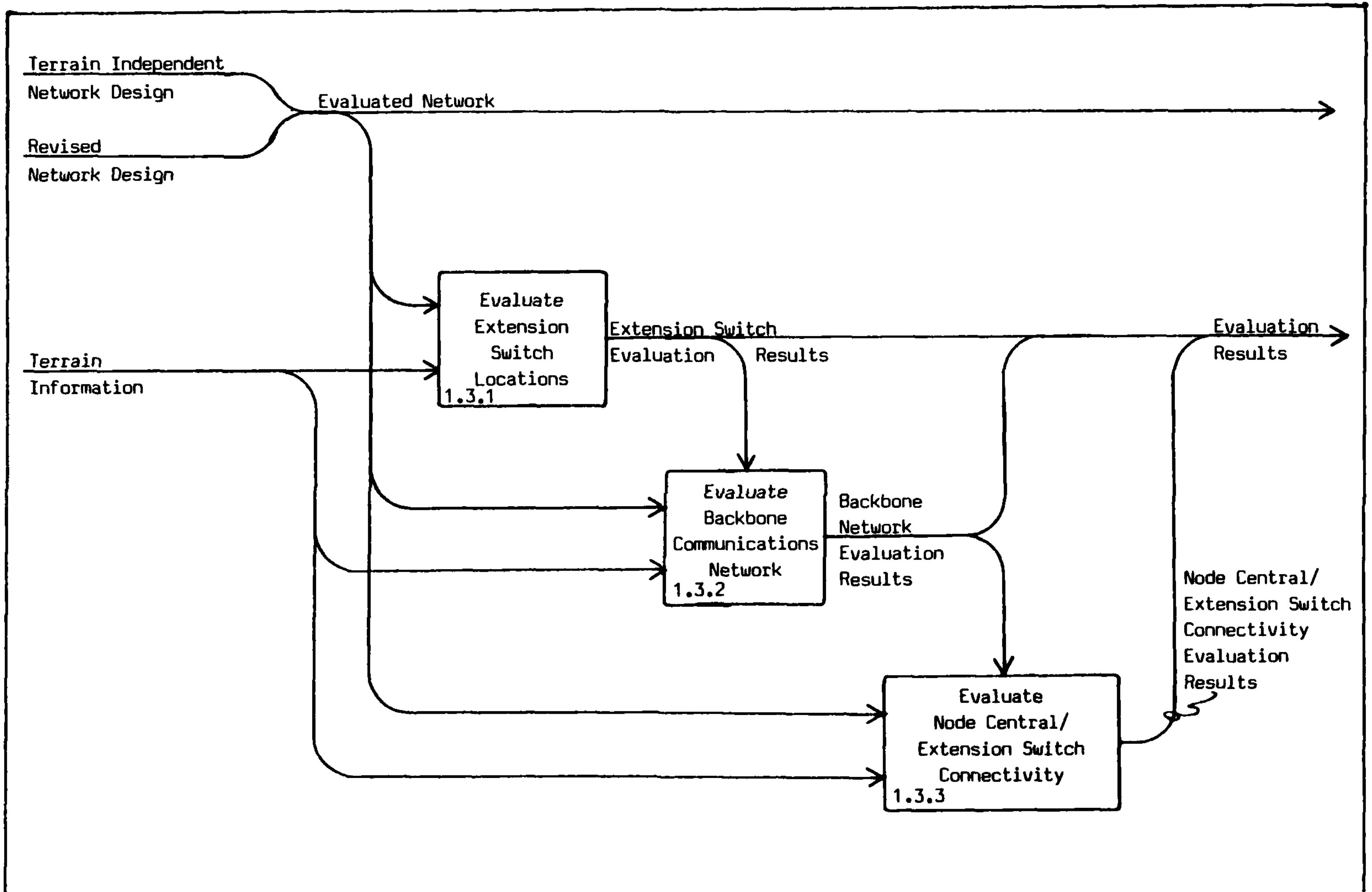


Figure 4. Network Evaluation (Decomposition of Block 1.3)

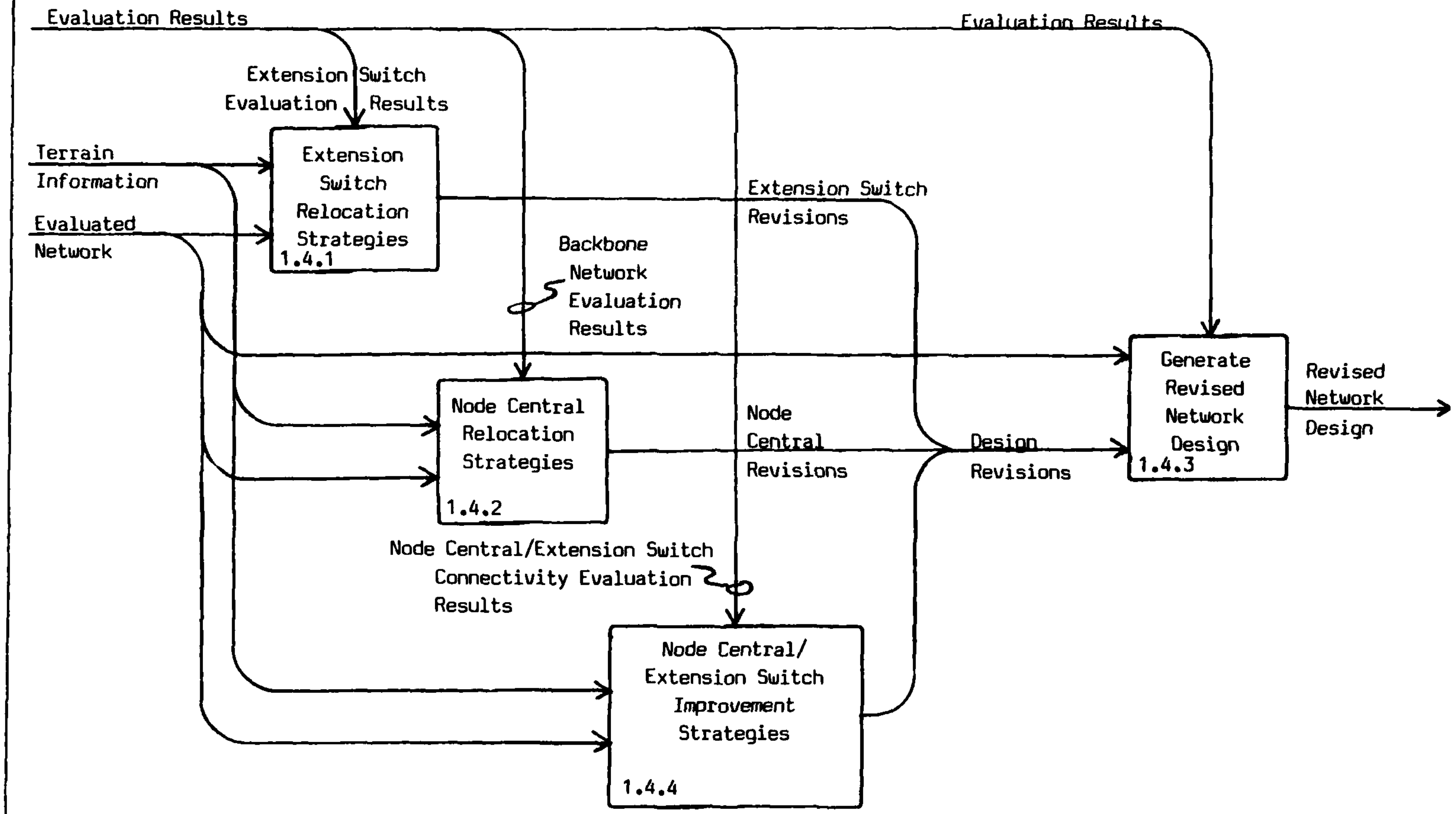


Figure 5. Design Revision (Decomposition of Block 1.4)

extension switch constraints are satisfied. Similarly, the connectivity between node centrals and extension switches is evaluated for constraint satisfaction only after all extension switch and backbone communications network constraints have been satisfied.

Extension Switch Location Evaluation. In the first phase of the evaluation process (Figure 6), each extension switch site is evaluated under two sets of criteria. First, each extension switch site is evaluated for constraint satisfaction relating to the terrain features associated with the selected site (block 1.3.1.1). Then the relative locations of each extension switch site are evaluated to ensure that multiple extension switches are not serving a unit population that could be served by a single extension switch (block 1.3.1.2). Switch locations are evaluated for constraint satisfaction in the order in which they were assigned.

The evaluation of each site to determine if terrain feature constraints are satisfied involves first extracting the relevant information about the potential site from each of the digital terrain databases to which MSENDS has access. Each of the extracted items of information is then individually checked to see if it satisfies proposed system constraints. Examples of terrain features that do not satisfy proposed system constraints include: steep slopes, terrain over which cross country movement cannot be accomplished, and water as the principle land cover. The range of information that is included in the five databases to which MSENDS has access is listed in Appendix B along with those categories that do not satisfy proposed system constraints.

Extension Switch Relocation Strategies. When an extension switch site is identified as not satisfying terrain feature constraints, the

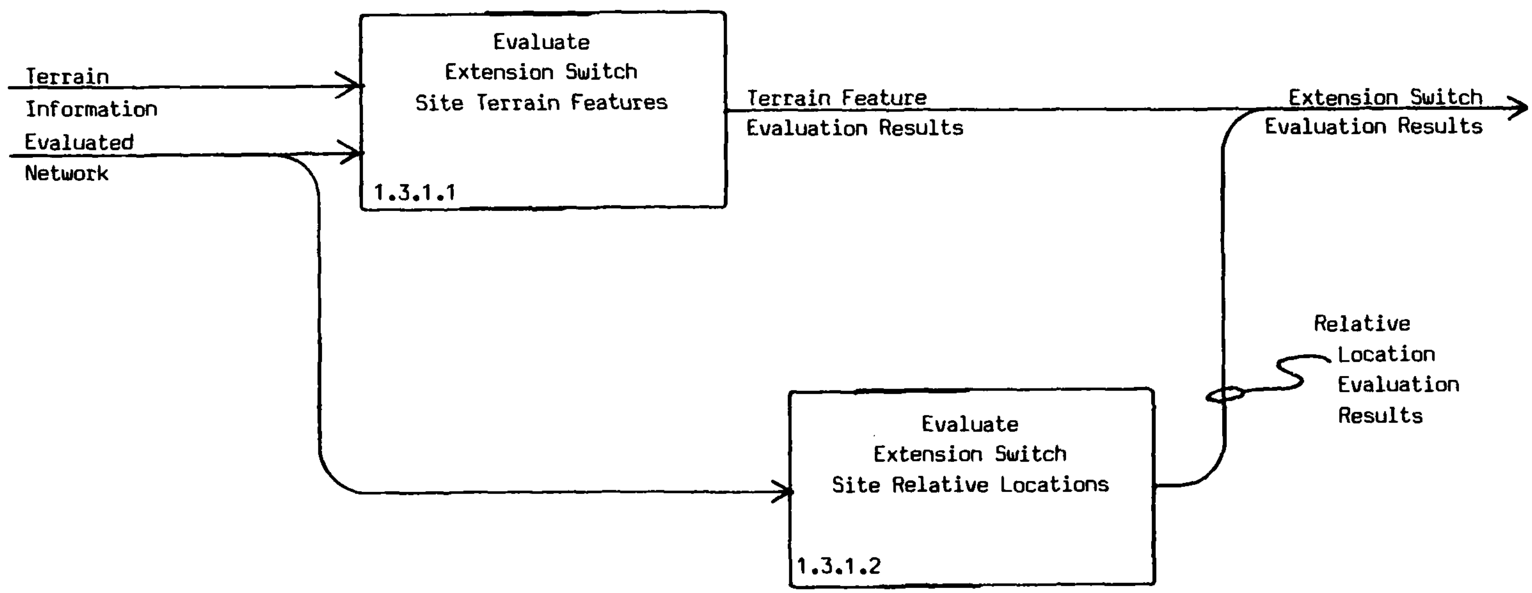


Figure 6. Extension Switch Location Evaluation (Decomposition of Block 1.3.1)

evaluation of the current design stops and an appropriate extension switch relocation strategy (Figure 7) is invoked. The first strategy used by MSENDS to select a new location is to search in the vicinity of the old location for a site that will satisfy terrain constraints (block 1.4.1.1). The area that may be searched is constrained by requiring that the new location be located no farther from the supported unit with the highest communications priority than the distance an extension switch can extend a junction box. If no acceptable location is found through the search strategy, the second strategy used by MSENDS is to request that the user either provide a location for the extension switch to MSENDS or provide a new location for the highest priority unit supported by that switch (block 1.4.1.2). If the user chooses to provide a site for the extension switch, that location is treated as if it meets all terrain constraints.

Changing the location of either an extension switch or the highest priority unit served by a switch requires that the design of the evaluated network be revised. Network design revision will affect that portion of the network that was designed after either the selection of the original site for the relocated extension switch or the assignment of the relocated unit to an extension switch. Design revision involves regenerating the initial terrain independent design beginning at the point in that process following the assignment of the extension switch that failed constraint evaluation. Thus, the design revision will include reselection of node central locations and formation of a new backbone communications network in a terrain independent manner.

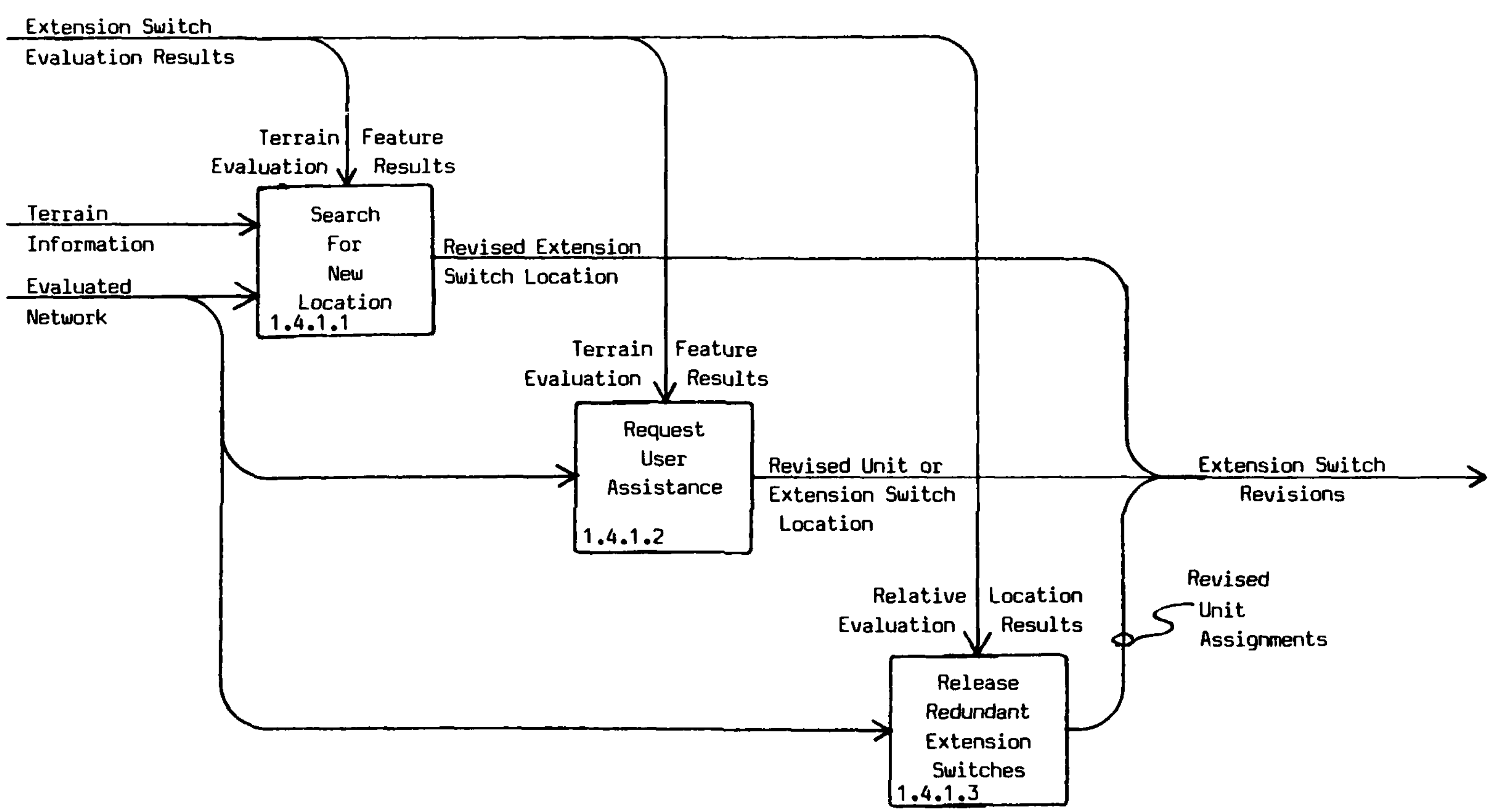


Figure 7. Extension Switch Relocation Strategies (Decomposition of Block 1.4.1)

Following completion of the revision, terrain constraint satisfaction evaluation continues from the first extension switch that was assigned in the system redesign.

Once the extension switch sites have been determined to satisfy terrain constraints, they are evaluated to determine if relative location constraints are satisfied (block 1.3.1.2). In evaluating a potential site's location in relation to other potential extension switch locations, the constraint that must be satisfied is that extension switches must not be located such that two or more switches serve a unit population that could be handled by a reduced number of extension switches.

The strategy used by MSENDS to resolve a situation in which two or more extension switches are found to be serving a unit population that can be served by a reduced number of switches (block 1.4.1.3) is to first identify the switch serving the unit with the highest communications priority. This switch will be retained at its location and all other switches serving the unit population in question will be released. Units that are collocated with the retained switch or collocated with junction boxes extended by the retained switch are assigned to the retained switch. Any other units that were assigned to either the retained switch or the released switches revert to an unassigned status.

If any extension switches have been released based upon the results of relative location constraint evaluation as described above, that portion of the terrain independent network that was designed after the last available extension switch was assigned to a high priority unit must be redesigned. The design revision is performed in the same manner as described above. Following the redesign, terrain constraint satisfaction evaluation continues from the first extension switch that was involved in the design revision.

Node Central Location Evaluation. After determining that the extension switch locations satisfy all terrain and location constraints, and no further redesign at the extension switch level is required, the second phase of the evaluation process begins. In the second phase, MSENDS evaluates the node central sites of the current network design for constraint satisfaction (Figure 8). Constraints that must be satisfied are of two types. First, each node central must be able to achieve connectivity with at least two, and not more than four, other node centrals to form the communications system backbone network. Second, each node central site must satisfy the same terrain feature constraints that extension switch sites were required to satisfy.

Site to site connectivity is evaluated by means of propagation prediction techniques, described in Chapter II, using the elevation information contained in the digital terrain databases to which MSENDS has access. First, each node central location in the current design is evaluated to determine if connectivity with any of the other node centrals to which it is connected to form the communications network backbone system can be established (block 1.3.2.1). If connectivity can be established, then the node central location being evaluated, and each of the locations with which it can achieve connectivity, are evaluated for terrain constraint satisfaction (block 1.3.2.2). If connectivity cannot be achieved, or if terrain constraints cannot be satisfied, MSENDS will attempt to adjust node central locations as required (Figure 9).

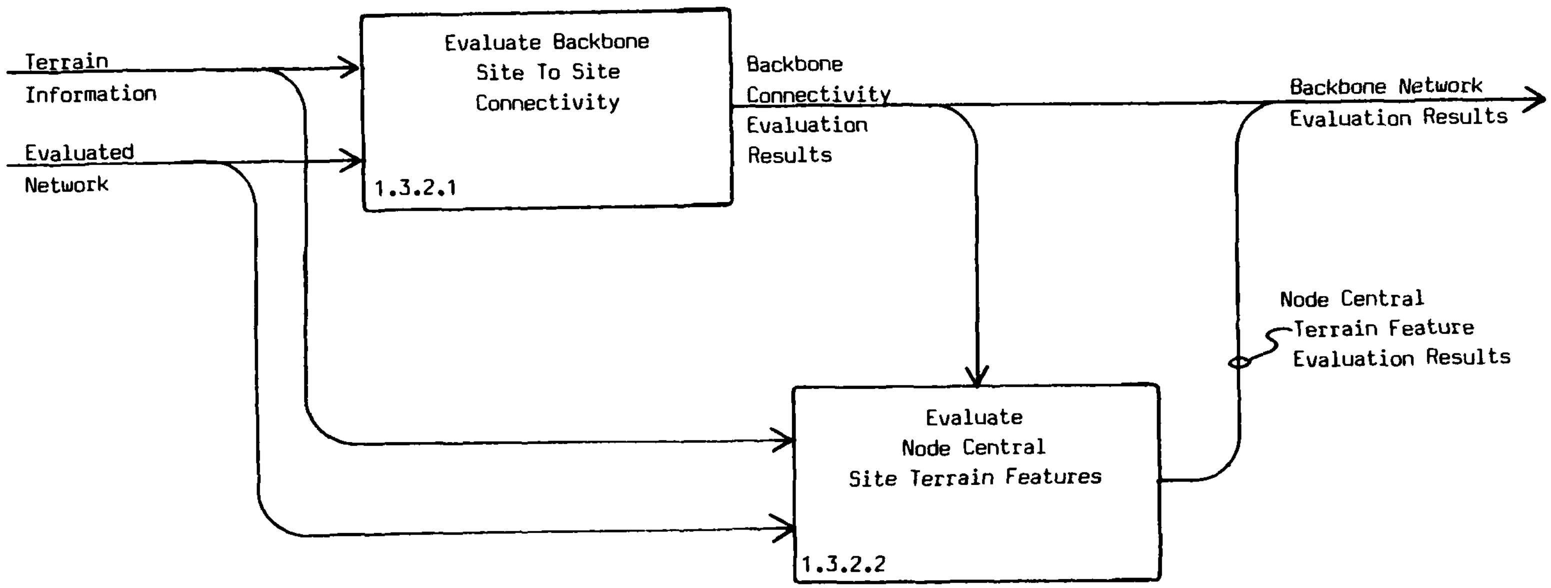


Figure 8. Node Central Location Evaluation (Decomposition of Block 1.3.2)

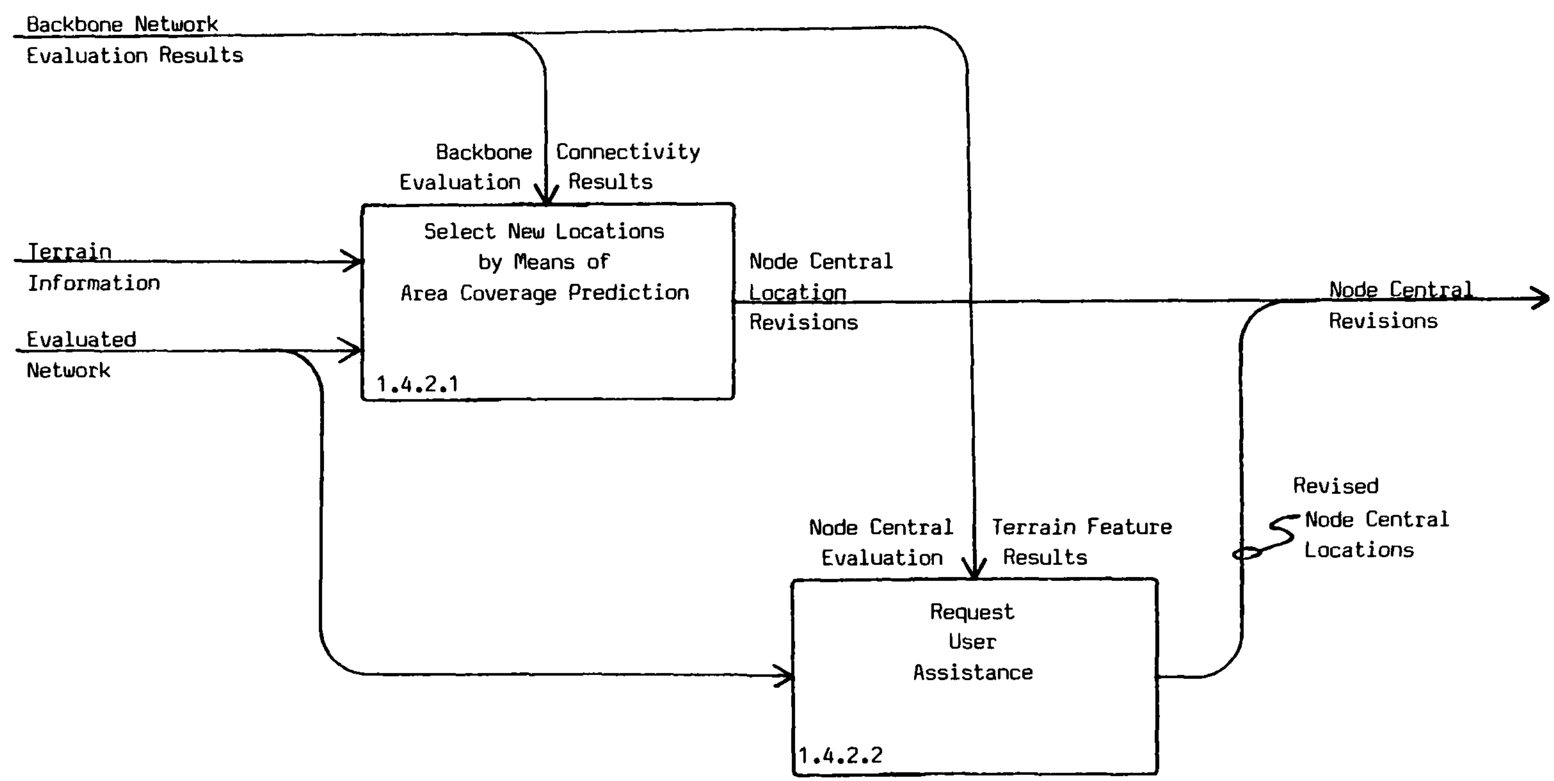


Figure 9. Node Central Relocation Strategies (Decomposition of Block 1.4.2)

Node Central Relocation Strategies. Any node central location that achieves the connectivity with each of the other node centrals required to form the backbone network, but fails to satisfy terrain evaluation constraints, is brought to the attention of the user (block 1.4.2.2). Similarly, any node central locations to which connectivity is achieved that fail to satisfy terrain constraints are also brought to the attention of the user. The user may either decide to ignore the fact that a node central location does not satisfy system terrain constraints and direct that the system accept the site, or the user may agree that the site is unacceptable. For sites determined to be unacceptable, the user may either direct that the system attempt to find an acceptable location, or the user may supply the system with a location. User supplied locations are considered to satisfy all terrain constraints but must still be evaluated for connectivity.

A node central location that satisfies terrain constraints and can achieve the connectivity required to form the backbone network is considered an accepted location by MSENDS. Node centrals that have connectivity to an accepted location, but cannot achieve the connectivity required for the backbone network are considered potential node central locations by MSENDS and are dealt with next.

From a potential node central location, area coverage propagation prediction techniques are used to identify locations that the potential node central under consideration can establish connectivity with (block 1.4.2.1). If locations identified in this manner are in the vicinity of any node centrals with which the potential node central must achieve connectivity to form the backbone network, then those node centrals are moved to the identified locations. This process of identifying new locations by means of area coverage prediction continues until either all backbone network connections are established or the system is unable to determine a location to which connectivity can be established. User assistance is requested if node centrals to which connectivity cannot be established exist.

If none of the node central locations selected during the initial design phase meet connectivity and terrain constraints, user assistance is requested (block 1.4.2.2). User assistance to form the backbone network consists of providing at least one potential node central location to the system and allowing the system to attempt to redesign the network accordingly. The user may also reduce the connectivity requirements of selected node centrals, as long as the connectivity of each node central is not less than two.

MSENDS will treat user provided sites as if they meet terrain constraints and only evaluate for connectivity. If connectivity cannot be established as required to form the communications backbone network, area coverage propagation prediction techniques will again be used to attempt to find sites, as described above. If suitable locations still cannot be found, further user assistance will be requested until a backbone communications network is established or the user terminates the design session.

Extension Switch to Node Central Connectivity Evaluation. Once the backbone network is established, the extension switches will be connected to node centrals to form the final communications system. If node central locations have been changed from the terrain independent system designed by the system, a redesign that involves the accepted node central locations and the accepted extension switch positions will be performed. Since all extension switches and node central locations have previously been evaluated for terrain constraint satisfaction, the only constraint that must be checked in this phase is connectivity between extension switches and node centrals.

If connectivity cannot be directly established between a node central and an extension switch, area coverage propagation prediction techniques are used to find potential locations at which to place a super-high frequency radio set to act as a radio relay (Figure 10, block 1.4.4.1). Each of the potential radio relay sites identified is then evaluated for terrain constraint satisfaction (block 1.4.4.2). If the system is unable to find a radio relay site that satisfies terrain constraints, MSENDS requests user assistance (block 14.4.3). The user may direct that terrain constraints be ignored and that the system accept one of the potential locations, or the user may provide the system with a location. User supplied locations are considered to satisfy all terrain constraints, but must still be evaluated for connectivity.

Locations that satisfy all constraint evaluations as described above are passed to the user in the form of a proposed MSE communications network design.

System Architecture

The architecture of the network design system proposed above is based upon the Redesign architecture set forth by Dixon, et al (13). The Redesign architecture has two basic components: an initial design phase and a redesign phase. The initial design phase provides a starting point for the redesign phase, which is an iterative process

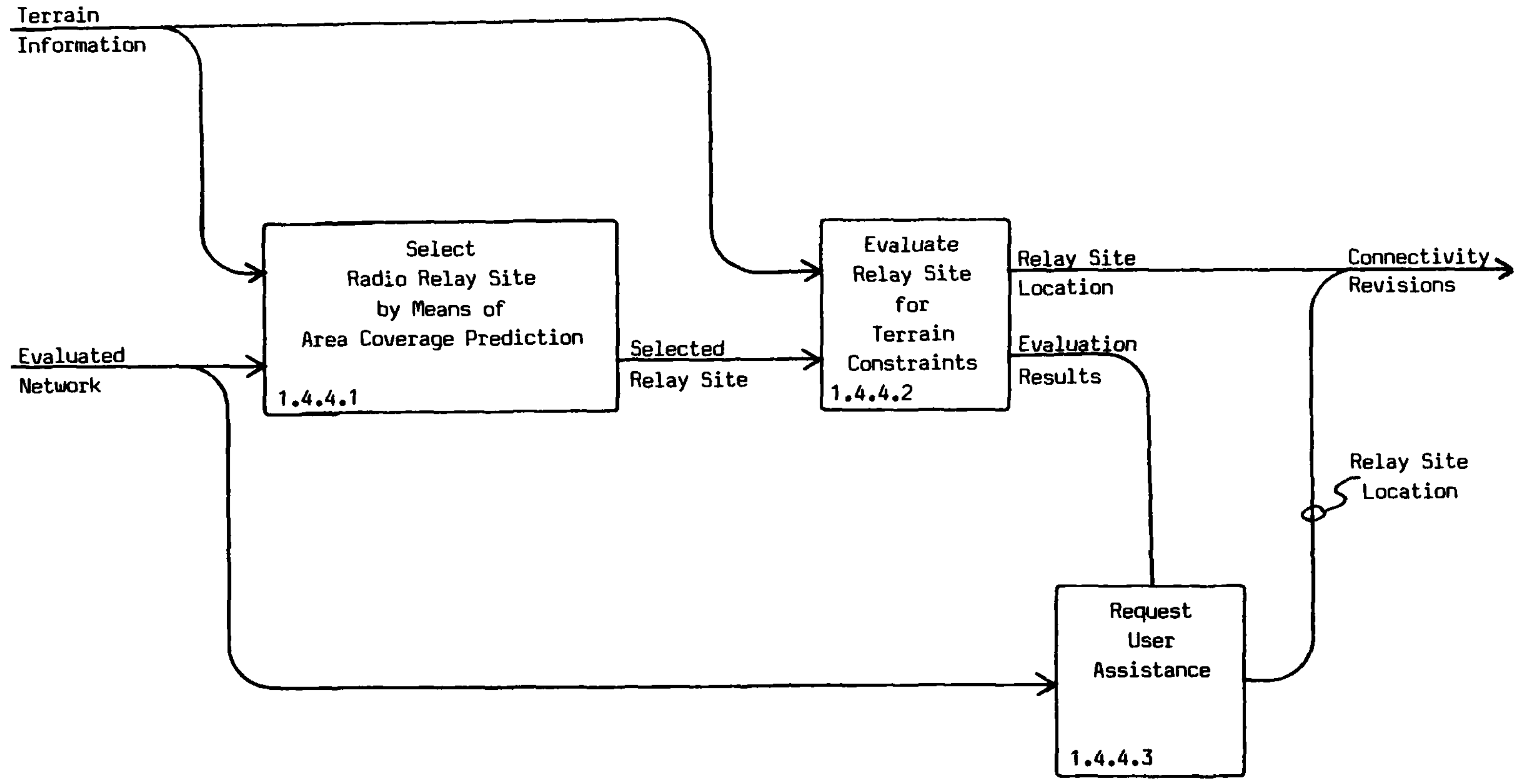


Figure 10. Extension Switch to Node Central Connectivity Evaluation (Decomposition of Block 1.4.4)

involving three steps: evaluating the current design, deciding if the current design is acceptable, and revising the current design if it is not acceptable (13:636).

MSENDS creates the terrain independent network, described above, as its initial design. The terrain independent network design is produced using a modified form of the multilevel clustering algorithm set forth by Schneider and Zastrow (32). A major difference between the Schneider/Zastrow algorithm and the proposed network design system lies in the use of unit communications priorities by MSENDS to collocate extension switches with the highest priority unit supported. If the Schneider/Zastrow algorithm as described in (32) were used, extension switch (or first level concentrator) locations would instead be selected between supported units, with the distance between each unit and the extension switch proportional to the number of terminals each unit possesses and the total number of terminals the extension switch is providing support to (32:6).

The iterative design revision phase of MSENDS is composed of the terrain feature and propagation prediction constraint satisfaction evaluation functions and the strategies used to select new locations when constraint satisfaction is not achieved. The network redesign strategy used by MSENDS is dependent upon which constraints are not satisfied. The constraints that must be satisfied and the strategies that the system may use were described above.

In addition to incorporating the concepts of the Redesign architecture, MSENDS also incorporates the concept of design specialists set forth by Brown and Chandrasekaran (3). Three design specialists are used to form the initial terrain independent network design. One specialist handles the selection of locations for each of the the extension switches and the assignment of subordinate units to the switches. Another specialist handles the selection of locations for the node centrals and the assignment of extension switches to the node centrals. The third design specialist forms the backbone communications network that connects the node centrals and completes the formation of the communications network.

The strategies used in the design revision phase also use design specialists. Specialists that are found within the system perform the tasks of locating new extension switch locations, new node central locations, and selecting locations at which to place super-high frequency radio sets. Should these specialists fail to select locations that satisfy required constraints, MSENDS requests that the user act as a design specialist and provide input from outside the system.

In the proposed system, the various design specialists are invoked as required by the system control strategy, and the design that is produced is evaluated by a set of what may be considered as evaluation specialists. None of the design specialists performs any type of constraint checking. This division of labor between design specialists and evaluation specialists differs from the manner in which Brown and Chandrasekaran proposed that the design specialists function (3:174-175).

Control Structure

The MSENDS control structure is data driven, using a blackboard architecture similar to that described by Hayes-Roth (19). The information contained on the blackboard is updated as each design specialist or evaluation specialist completes its action. Based upon the information currently on the blackboard, a scheduling specialist determines the next action that the system must perform. This architecture supports the strategies used in the design revision phase of the proposed system.

The strategies that MSENDS uses to redesign the communications system are based on the concept of non-chronological backtracking (41:82-84). From the information contained on the blackboard, the scheduling specialist is able to determine the current state of the proposed system. Knowing the state of the proposed system enables the scheduling specialist to invoke the correct design or evaluation specialist.

Each specialist has access to (is able to view) the blackboard, and can therefore determine what design or evaluation steps to perform. As each specialist performs actions that alter the state of the proposed system, a copy of the current blackboard contents are stored. Some examples of state altering actions include the assignment of individual extension switches to high priority units and the selection of a location for a node central.

Based upon the results of the evaluation specialists, an appropriate redesign strategy is invoked. Each strategy involves starting the redesign effort following the assignment of the last item of MSE system equipment that is at a location that satisfies all constraints. Rather than working backwards step by step from the final design action to the point in the design process at which the redesign is to begin and undoing each individual design action, the stored contents of the blackboard can be used to reinstantiate the state of the system at the desired point in the design process from which the redesign action is to begin.

A prototype system that implements the redesign architecture and the control structure supporting non-chronological backtracking, as described above, is presented in the next chapter.

IV. Prototype System Design

A prototype of the Mobile Subscriber Equipment Network Design System (MSENDS) described in the previous chapter was developed to validate the proposed system architecture and control structure. This prototype, referred to hereafter as MSENDS-P (Mobile Subscriber Equipment Network Design System - Prototype), implements portions of each of the four main functional blocks of MSENDS (Figure 2, page 31).

The primary difference between MSENDS and MSENDS-P is that terrain information is not available for use by MSENDS-P. Therefore, MSENDS-P performs neither the terrain feature evaluations nor terrain dependent connectivity evaluations that are described in the Evaluate Network Design action (block 1.3, page 31) of MSENDS. The network design that is created by MSENDS-P is terrain independent.

By making MSENDS-P terrain independent, the data driven blackboard architecture that controls the design, evaluate, redesign cycle could be observed with a minimum of user interaction required. In addition, the terrain independent network design that was proposed by MSENDS-P could be compared to a terrain independent network proposed by a second system that used only the Schneider/Zastrow algorithm (32).

The remainder of this chapter describes the implementation of MSENDS-P. The reasons for choosing ROSS, the language in which MSENDS-P is written, are presented first. Next, a description of the types of objects that make up MSENDS-P and how these objects relate to the proposed MSENDS design is presented. This is followed by a discussion of the MSENDS-P states and state transitions. Finally, a detailed description of the operations performed within MSENDS-P is presented.

The ROSS Language

The ROSS language is an object oriented programming language that was developed at the Rand Corporation. It was originally designed for the purpose of constructing simulations and is particularly well suited to representing complex real world systems (25). The version of ROSS used to implement MSENDS-P is implemented in Franz LISP (15) and hosted on a VAX 11-780 running UNIX, Berkeley 4.2 BSD.

Within ROSS, real world objects are represented by programming constructs, known as actors, that are created hierarchically. This hierarchical approach enables complex real world systems to be represented in a top down fashion, with each level in the hierarchy representing a further level of decomposition. The hierarchical structure of ROSS also enables inheritance mechanisms to be used to associate common properties with an entire class of actors.

Actors in ROSS may perform operations and store information. The operations an actor may perform are known as its behaviors. Each behavior consists of functions that are performed when the behavior is invoked. The set of functions that make up a particular behavior may be composed of ROSS functions, LISP functions, or any combination of ROSS and LISP functions. Behaviors may be explicitly defined for an actor or may be inherited by an actor from its ancestors.

Information is stored by an actor as a set of attributes. Each attribute may have a single value or a list of values associated with it. As with behaviors, an actor's attributes may be set explicitly, or may be inherited by an actor from its ancestors. Explicitly setting the value of an actor's attribute will override the inheritance mechanism for that particular value.

Actors are of two types: generic actors and instance actors. Generic actors represent a set of objects that share common characteristics, while instance actors represent specific elements of the set of objects represented by a generic actor. In general, the actor hierarchy may be thought of as a tree structure, with instance actors being leaf nodes and generic actor being branch nodes. However, the ROSS actor hierarchy differs from a true tree structure in that it is possible for an actor to have multiple parents, enabling tangled hierarchical structures of great complexity to be constructed.

Processing in ROSS is controlled by passing messages between actors. An actor may send and receive messages from both itself and other actors. An actor will respond only to those messages directed to it and for which it has a defined behavior. Thus, a real world system is represented as a set of actors with the actions of the system represented as messages passed between actors that invoke appropriate responses.

ROSS was selected as the language in which to develop MSENDS-P for three main reasons. First, the hierarchical structure of ROSS enables the real world relationships of the units and equipment that make up a communications network to be logically represented. Second, the object oriented nature of ROSS, and the use of message passing between objects to control processing, enables a data driven system to be easily designed. Finally, ROSS provides a powerful set of operations for handling symbolic data and performing pattern matching operations, and, since ROSS is implemented in Franz LISP, it has the full set of Franz LISP operations available to it and thus the extensibility that is inherent to LISP.

MSENDS-P Objects

The top-most actor within the ROSS language, known as "something," is used to create the highest level MSENDS-P actor. This actor is known as "MSENDS" and is the parent of four actors at the first level of decomposition for the network design system (Figure 11) . The MSENDS actor has two principle functions: it is the actor that directs the start up of the design system, and it provides top level control to the entire design system.

Each of the actors at the first level of decomposition is the ancestor of a class of actors whose functions are either to store information or to perform system operations. Two types of information, or knowledge, are stored within MSENDS-P. Problem-workspace type actors store information generated within MSENDS-P as the design process progresses. Domain-object type actors store information about the real world items of equipment that make up the MSE communications system and the real world units that provide and receive the MSE system communications support.

System operations are performed by scheduler and knowledge-source type actors. Scheduler type actors use the knowledge stored by problem-workspace type actors to determine the current state of the system. Having determined the current state of the system, an appropriate knowledge-source type actor is selected to perform an operation that will change the state of the system.

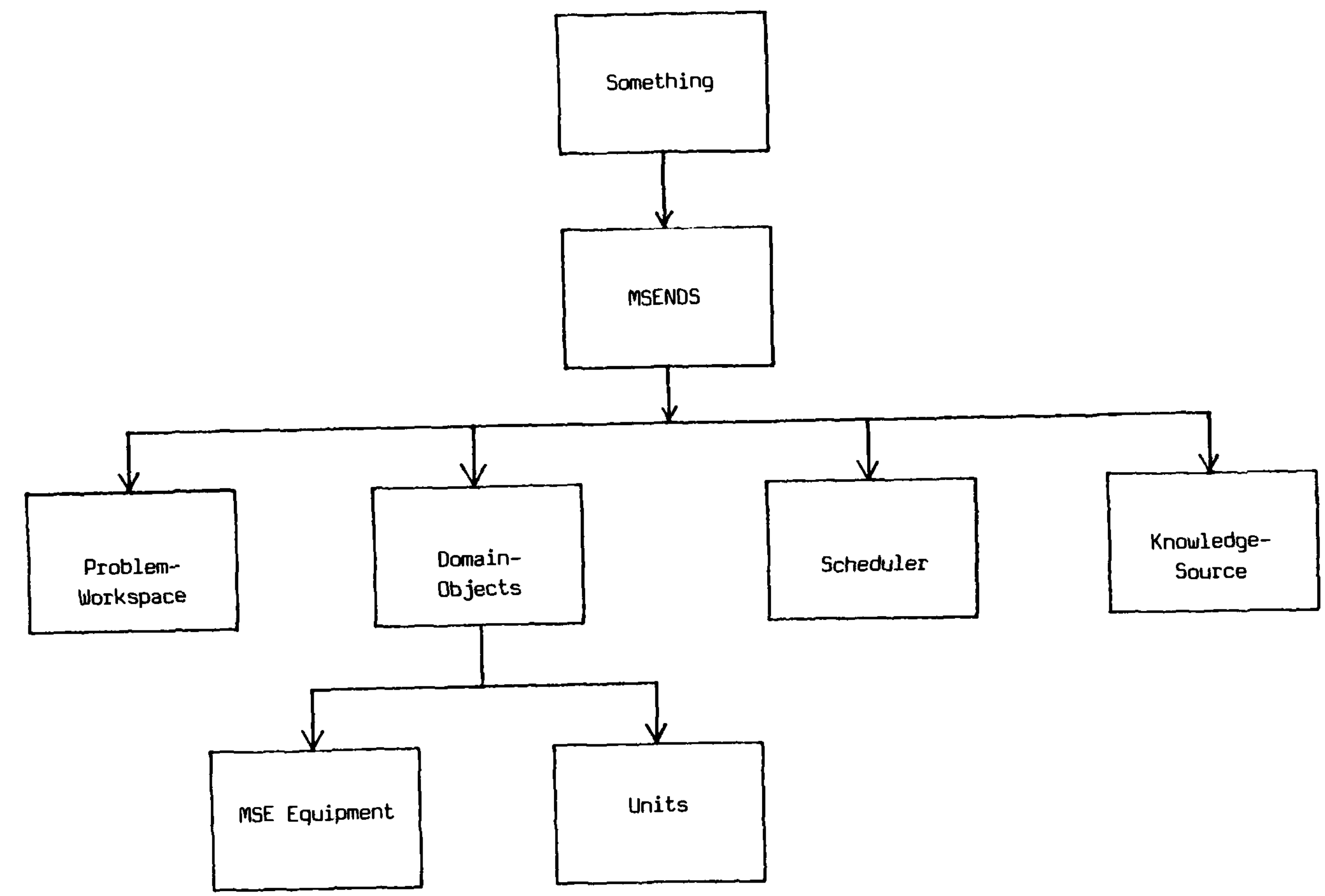


Figure 11. Top Level Actors for MSENDS-P

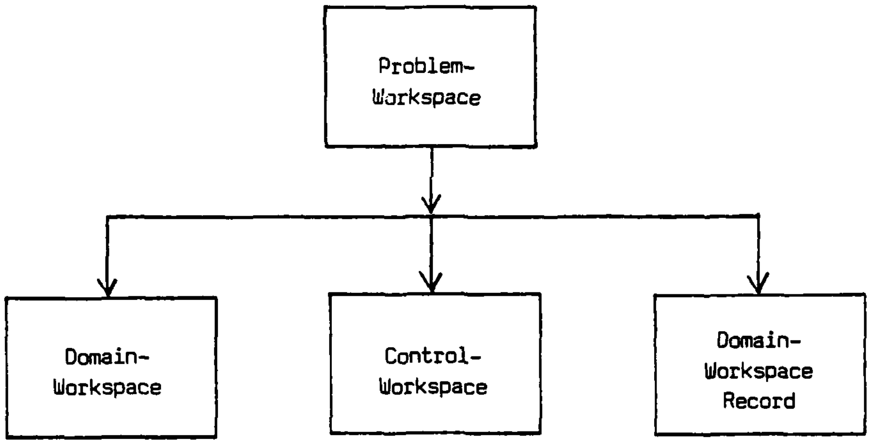
Problem-Workspace Type Actors (Figure 12a). Two types of system knowledge are stored in the three problem-workspace type actors. The Domain-Workspace actor stores knowledge that the system uses in the actual network design process while the Control-Workspace actor stores information that is used to control the network design process. Both the Control-Workspace actor and the Domain-Workspace actor act as blackboards, providing global storage for information throughout MSENDS-P.

The Domain-Workspace-Record actor stores copies of the domain-workspace blackboard. These copies are used to reinstantiate the state of the system as it existed when the copy was made and are what enable non-chronological backtracking to be implemented within MSENDS-P.

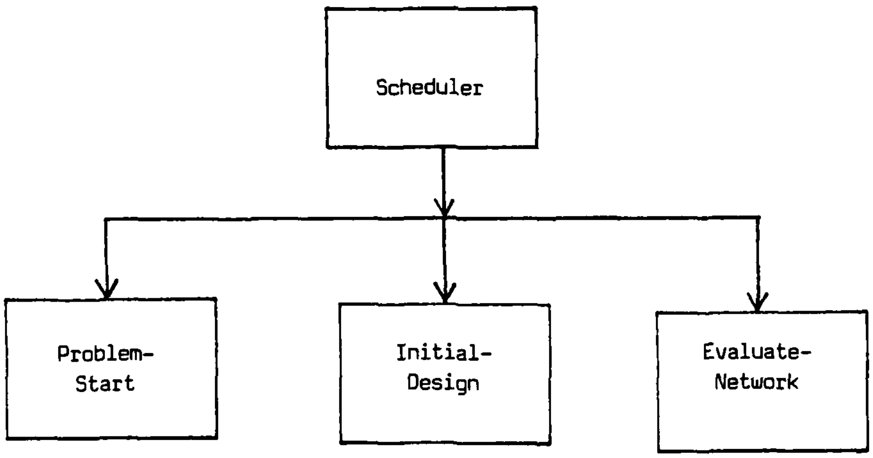
A detailed description of each of the Control-Workspace and Domain-Workspace actors is presented in Appendix C. These descriptions provide a list of the attributes for each actor and a description of each attribute.

Scheduler Type Actors (Figure 12b). The three scheduler type actors directly reflect the three principle states, known as contexts, that MSENDS-P may be in. The operations that may be performed during each of these three contexts directly reflect the four main actions performed by MSENDS (Figure 2, page 31).

As the name indicates, the Problem-Start actor identifies states and selects operations to be performed during the MSENDS-P start up context. The operations that will be selected involve asking the user to provide information about the supported and supporting units and thus correspond directly to the Accept User Input action of MSENDS.



(a) Problem-Workspace Offspring



(b) Scheduler Offspring

Figure 12. Problem-Workspace and Scheduler Offspring

The Initial-Design actor identifies the states and selects operations to be performed as a design for the communications network is being created. Because MSENDS-P is totally terrain independent, the design created the first time the Initial-Design actor is invoked corresponds to the design created by the Generate Initial Network action of MSENDS.

When a complete design has been generated, the Evaluate-Network actor identifies which portions of the network design must be evaluated and selects the appropriate tests to be performed. The states identified and the actions selected by the Evaluate-Network actor correspond to the Evaluate Network Design action of MSENDS.

Since MSENDS-P is terrain independent, an explicit actor that performs the redesign operations is not required. Instead, the redesign operations within MSENDS-P are performed by the Initial-Design actor. Using the domain-workspace blackboard copies stored by the Domain-Workspace-Record actor, design revisions can be performed by reinstantiating the appropriate system state and allowing the Initial-Design actor to perform its normal operations.

Thus, it can be seen that the four actions identified at the first level of decomposition of MSENDS have been implemented within MSENDS-P.

Knowledge-Source Type Actors (Figure 13). Knowledge-Source type actors are experts at performing specific tasks. They are invoked by the scheduler type actor corresponding to the current system context.

The User-Input actor, as the name implies, specializes in providing the interface between MSENDS-P and the user. The operations that the User-Input actor performs are primarily invoked during the problem-start context to provide MSENDS-P with the composition and identity of the

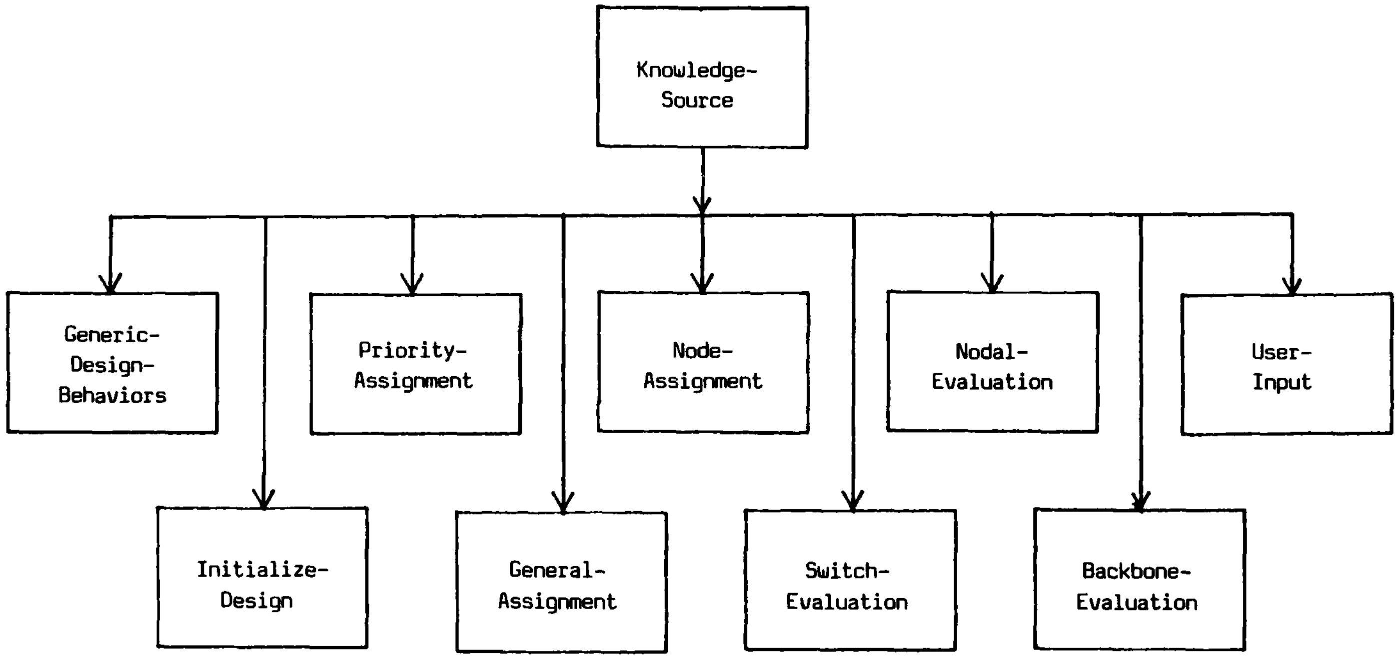


Figure 13. Knowledge-Source Offspring

combat force that requires communications support and the signal unit providing the support.

Within MSENDS, the Generate Initial Network action was decomposed into three distinct phases (Figure 3, page 33). Each of the Knowledge-Source type actors in MSENDS-P that perform design tasks specialize in operations that are appropriate to one or more of the phases identified in MSENDS.

The Initialize-Design actor specializes in preparing the system for the design task. This actor is invoked after the user has identified the combat force and the signal unit to the system. The operations performed by the Initialize-Design actor result in information being extracted from domain-objects type actors and placed on the domain-workspace blackboard.

The selection of extension switch locations is performed by the Priority-Assignment actor. Extension switch locations are selected to provide support to units with high communications priority in the same manner as described for MSENDS. After all available extension switches have been assigned locations to support units with high communications priority, the General-Assignment actor assigns any remaining units to the nearest switch with available capacity.

The Node-Assignment actor performs the operations associated with the selection of node central locations and the formation of the communications backbone network. Design operations that are not specific to one of the four design actors already described are performed by the Generic-Design-Behaviors actor.

The remaining knowledge-source type actors specialize in the evaluation of completed network designs. Of the three evaluation phases identified in MSENDS (Figure 4, page 35), only the evaluation of extension switch locations can be performed without access to terrain information. Therefore, although three evaluation experts exist within MSENDS-P, only the Switch-Evaluation actor performs any actual operations. The evaluation operations performed by the Switch-Evaluation actor are those dealing with the evaluation of relative switch locations.

Domain-Objects Type Actors. The real world objects represented by the domain-objects type actors are divided into two main classes: Units and MSE-Equipment (Figure 11). The MSE-Equipment type actors (Figure 14) store information that describes the types of MSE equipment presented in Appendix A. Although actors are instantiated for each type of equipment available within the MSE system, MSENDS-P deals only with instance actors of the node-central, large-extension-switch, and small-extension-switch types.

The units type actors are further subdivided into signal-unit type actors and combat-force type actors. Two of the signal-unit type actors provide communications support to combat forces: the Division-Signal-Battalion actor and the Corps-Signal-Brigade actor. The communications network that is provided by a real world corps signal brigade is composed of equipment provided by both corps area signal battalions and division signal battalions. Thus, a Corps-Area-Signal-Battalion actor is also provided.

The user must provide the system with the type and identity of each supporting signal unit. If the supporting signal unit is a Corps-Signal-Brigade actor, the user must also specify that actor's subordinate units and their type. Since MSE system equipment is

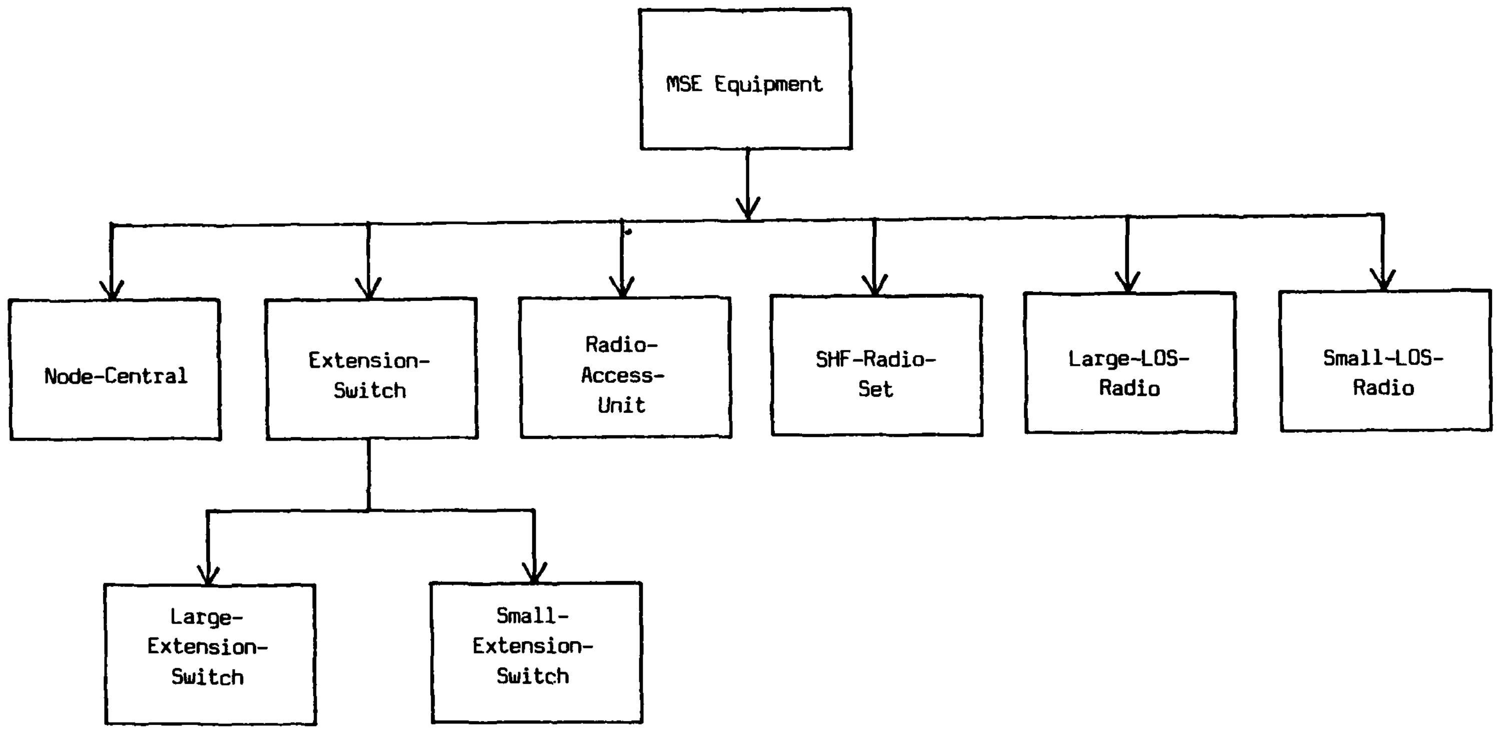


Figure 14. MSE Equipment Offspring

doctrinally assigned to signal units, these quantities are specified in the attributes of each of the specific signal-unit type actors. Thus, knowing the type and number of signal units providing support to a combat force enables the amount of available MSE system equipment to be calculated within MSENDS-P.

Combat-force type units are further subdivided into corps type units and division type units (Figure 15), each of which are further subdivided to the subordinate unit level (Figure 16) . Actors of type "units" that are subordinate to the Corps and Division actors represent the real world units that are to be supported by the MSE system. Communications priorities and the number of terminals a type "units" actor possesses are specified by that actor's attributes. Instances of subordinate type "units" actors that reflect real world units are created using information supplied to MSENDS-P by the user.

A detailed description each actor that has the Domain-Objects actor as an ancestor is presented in Appendix C. The attributes of each actor and a description of each attribute is presented.

MSENDS-P States and State Transitions

At the highest level of MSENDS-P, the MSENDS actor maintains executive control over the transitioning between states within the system. This executive control is accomplished by iterating through a simple looping construct that begins when the user directs the start up of MSENDS-P and terminates when a system state in which a design that satisfies all evaluation criteria exists.

The first step performed by the MSENDS actor from within the executive control loop is to send a message to the Scheduler actor

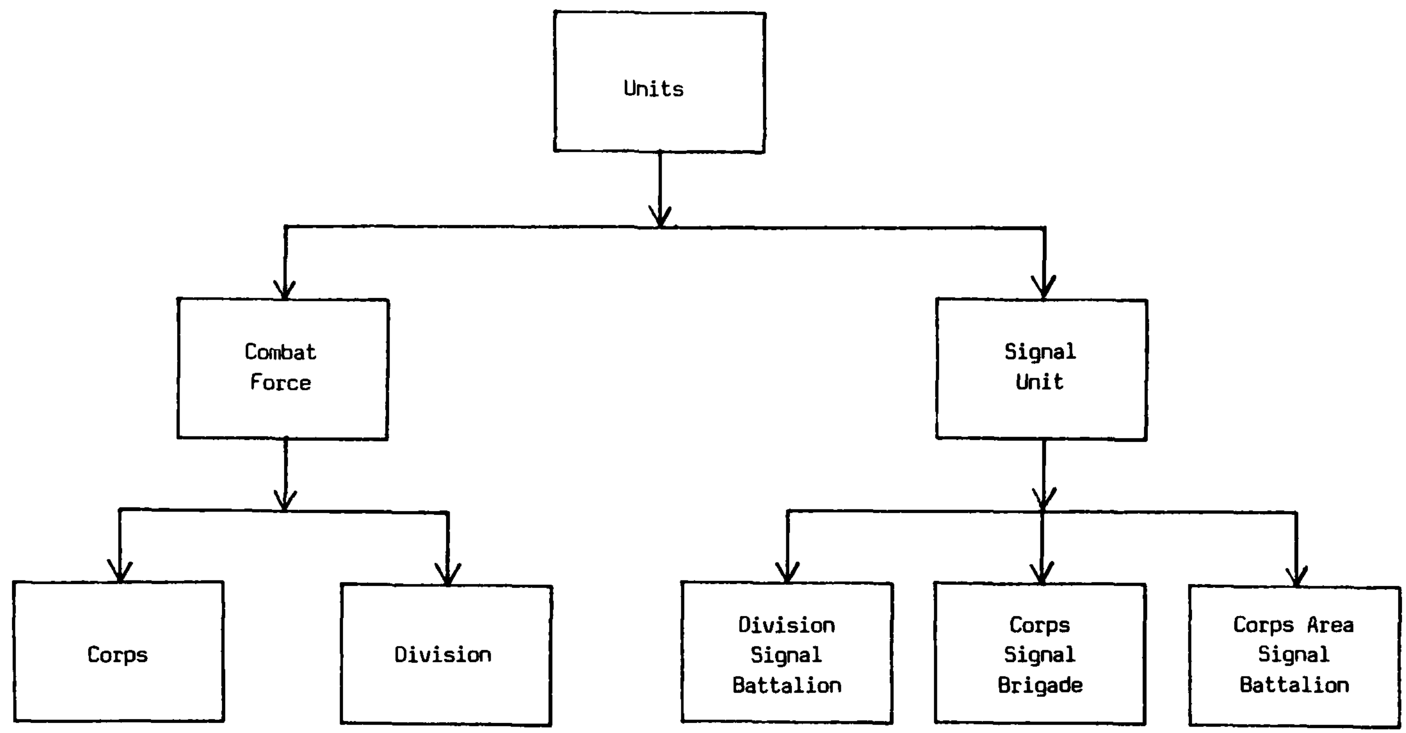


Figure 15. Units Offspring

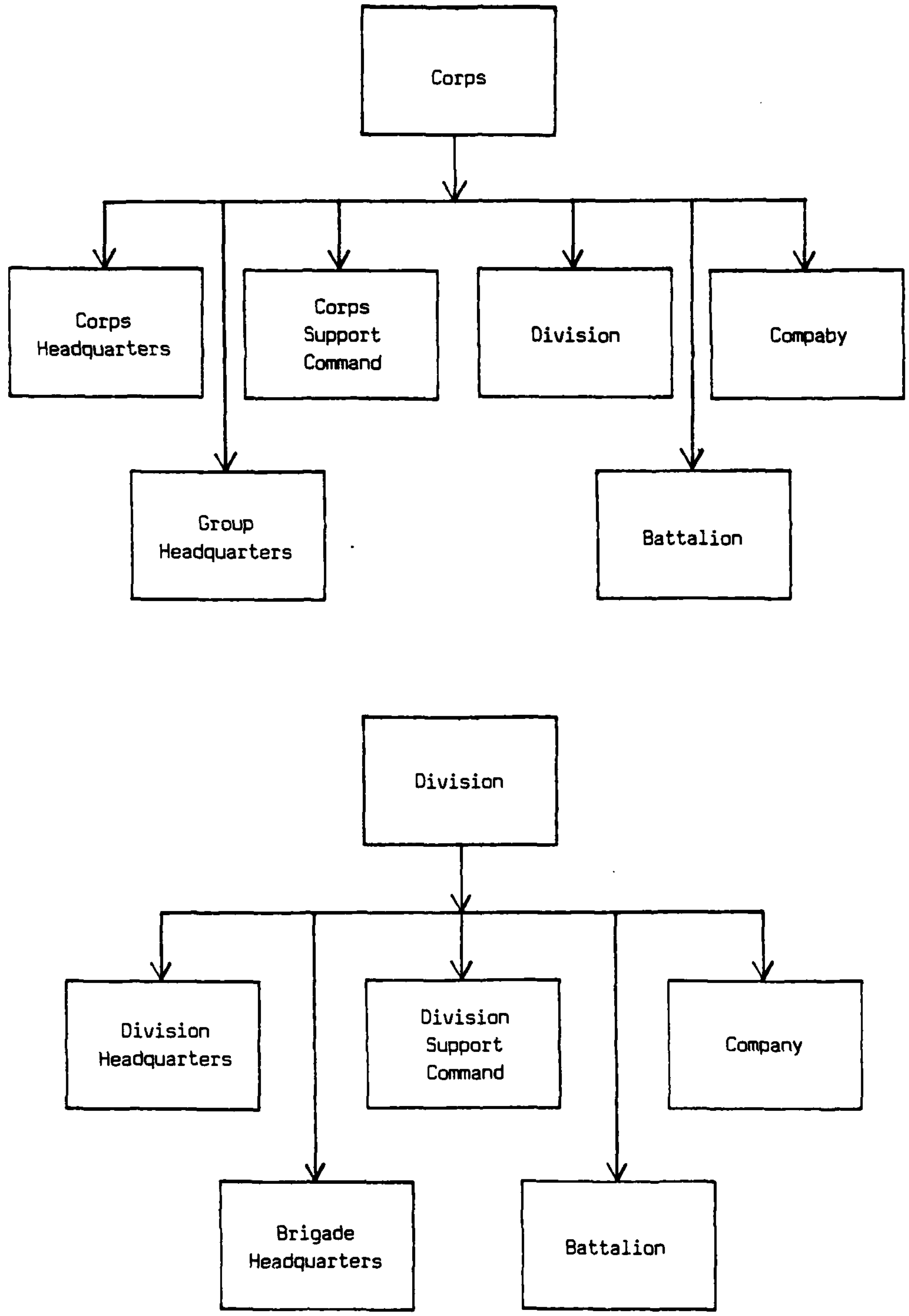


Figure 16. Combat Force Offspring

directing that the current system context be determined and the scheduler type actor corresponding to the current context be directed to select an appropriate operation to change the current state of the system. When control returns to the executive loop, the MSENDS actor checks to see if the current system context indicates that a satisfactory design has been found. If the current system context does indicate that a satisfactory design has been found, the MSENDS actor terminates the system. If a satisfactory design has not been found, the final step in the executive loop is performed, and the MSENDS actor sends a message to the Scheduler actor directing that the operation determined appropriate by the currently active scheduler type actor be performed.

The three contexts, or principle states, of MSENDS-P correspond to the currently active scheduler type actor (Figure 17) . Thus, at system startup, the currently active scheduler type actor is the Problem-Start actor and the system context is therefore referred to as "problem-start." The actions performed while the system is in the problem-start context are those associated with initializing the system. The primary source of initialization information is the user, and the actor specializing in performing the user interface operations is the User-Input actor.

Once the information required to initialize the system has been input by the user, the currently active scheduler type actor becomes the Initial-Design actor. The system context therefore transitions to the "initial-design" context. While in this context, the design specialists Initialize-Design, Priority-Assignment, General-Assignment, and Node-Assignment are invoked sequentially in the order listed to form a

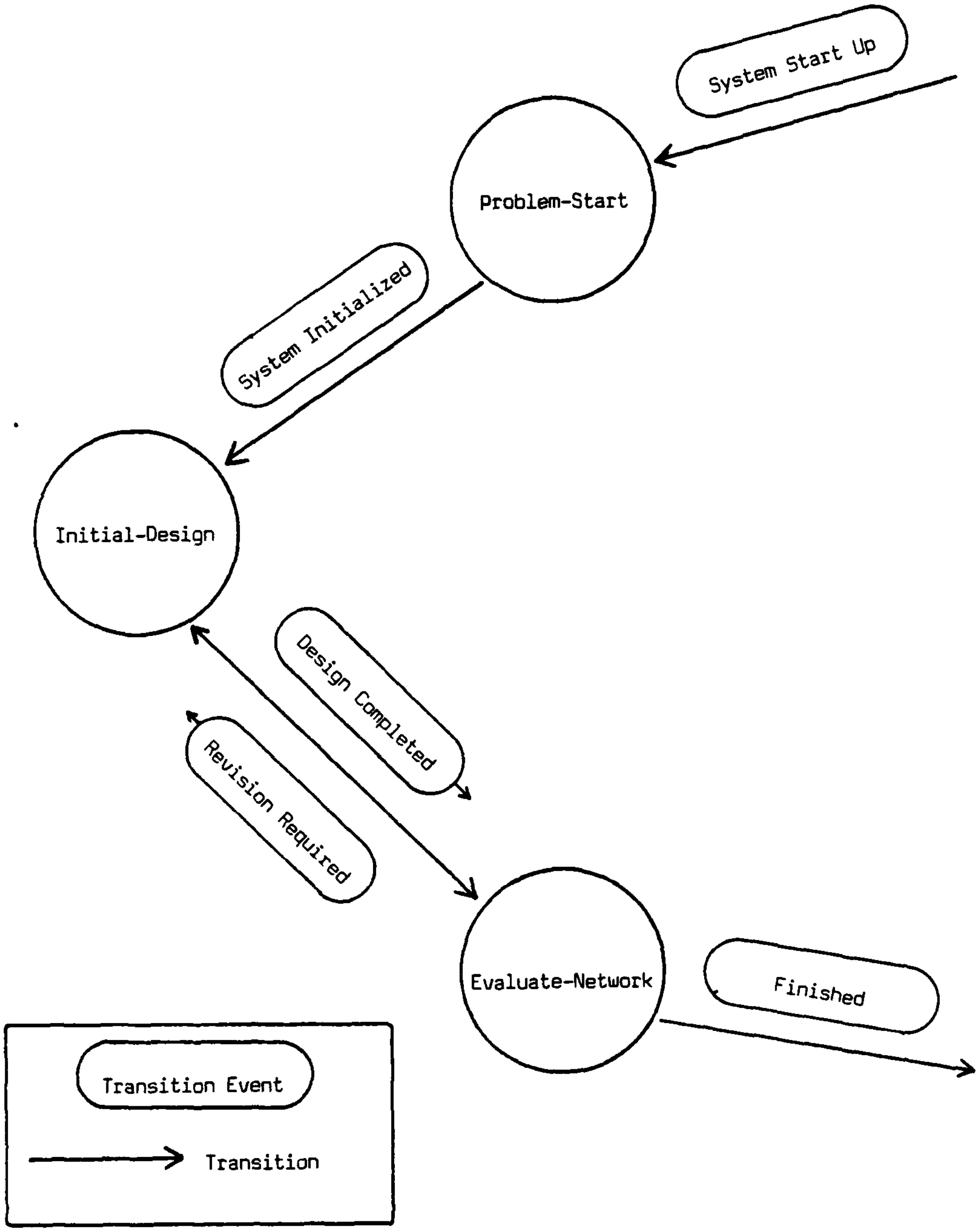


Figure 17. MSENDS-P Contexts and Transitions

network design. The knowledge-source type actor Generic-Design-Behaviors may be invoked by any of the design specialists to perform some action that is common to more than one stage of the design process.

When a design is produced, the currently active scheduler type actor becomes the Evaluate-Network actor, indicating that the context has transitioned to "evaluate-network." As stated earlier, the only active evaluation specialist in MSENDS-P is the Switch-Evaluation actor, and the only constraints that must be satisfied relate to relative switch locations. If the Switch-Evaluation actor detects a condition that does not satisfy a relative location constraint, an appropriate redesign strategy is invoked and the system transitions back to the initial-design context to perform a design revision. If, on the other hand, the Switch-Evaluation actor determines that all constraints are met, then the design is finished and the system transitions to the termination state.

Actor Operations

Scheduler Type Actor Operations. Three principle operations are performed by scheduler type actors: recognizing when a context transition is appropriate, identifying the currently active knowledge source type actor, and determining an operation for the currently active knowledge source type actor to perform. The information stored by the Domain-Workspace actor provides the means for the scheduler type actors to determine which of the three operations is appropriate.

The first system context, problem-start, is recognizable by the fact that no information about either the combat force or the signal unit is present on the domain-workspace blackboard. The Problem-Start actor invokes the User-Input specialist with appropriate operations until the user has provided information concerning both the combat force that the communications system is being designed to support and the signal unit which will provide the communications support to the system. As soon as combat force and signal unit information is posted to the domain-workspace blackboard, the Problem-Start actor indicates that a transition to the initial-design context is appropriate.

During the initial design context, nine types of information on the Domain-Workspace blackboard are analyzed by the Initial-Design actor to determine if a context transition is appropriate or if a knowledge-source type actor should be invoked. The data items from the domain-workspace blackboard that are considered, and the status of each item that will cause a specific knowledge source actor to be invoked, or a transition to the evaluate-network context to be made, are listed in Table I. (For a list and description of all the attributes of the Domain-Workspace actor see Appendix C.)

Within Table I, each column gives the status of the attributes that, in combination, determine whether a knowledge-source type actor will be invoked or if a context transition should be made. Those states that cannot be defined by the conditions of columns one through four invoke the Initialize-Design actor by default.

Table I. Initial Design States

Blackboard Attribute	Appropriate Action 1	2	3	4	5
unit-priority-pairs	A	A	0	0	:
unassigned-units	A	A	0	0	O
impossible-to-assign-units	x	A	x	x	T
unassigned-large-extension-switches	B	0	x	x	H
unassigned-small-extension-switches	B	0	x	x	E
assigned-extension-switches	x	1	x	0	R
unassigned-node-centrals	1	1	C	x	S
assigned-node-centrals	0	0	C	0	:
backbone-nodes	x	x	C	1	:

0 ==> No entries for attribute (value nil)
1 ==> At least one entry (value not nil)
x ==> Attribute is irrelevant (don't care value)
AA, BB, CCC ==> At least one of the same lettered attributes within a column must have an entry
OTHERS ==> Any combination of attributes not accounted for in the other four columns

1 : Invoke Priority-Assignment actor
2 : Invoke General-Assignment actor
3 : Invoke Node-Assignment actor
4 : Transition to *evaluate-network* context
5 : Invoke Initialize-Design actor

The Evaluate-Network actor performs its operations in essentially the same manner as the other two scheduler type actors. The only difference is that the Evaluate-Network actor examines the value contained in each of the attributes that it uses to make its determinations, rather than checking only for the presence or absence of a value. The three attributes that the Evaluate-Network actor examines are switch-status, nodal-status, and backbone-status. If the switch-status attribute has no entries, then the Switch-Evaluation actor is invoked. If the switch-status attribute has an entry, and that entry has the symbol value "reconciled," then, since no node location or backbone network evaluations are performed by MSENDS-P, the design is finished and a context transition to the terminated state is appropriate. If the switch-status entry value is other than "reconciled," then a transition back to the initial-design context is appropriate to enable network design revision to be performed.

Knowledge-Source Type Actor Operations. The operation that will be performed by each of the knowledge-source type actors is also determined by the absence or presence of information in one or more of the domain-workspace attributes.

Priority-Assignment Actor. The action that the Priority-Assignment actor will take is dependent upon the status of the unassigned-units attribute. If that attribute has entries, then an attempt to assign a switch to a unit will be made. If, on the other hand, that attribute has no entries, then the unit or units with the highest communications priority will be identified from among those units that have not been assigned to an extension switch.

The method used by the Priority-Assignment actor to assign a switch to a unit is based upon the the clustering algorithm proposed by Schneider and Zastrow (32) and the heuristic method described earlier for MSENDS. The unassigned-units attribute of the domain-workspace blackboard contains a list of the highest communications priority units currently not assigned to an extension switch. The assigned-extension-switches attribute contains a list of those extension switches that have been assigned a location to support one or more units.

Each unit in the unassigned-units list is first paired with each switch on the assigned-extension-switches list. Then each unit on the unassigned-units list is paired with each of the other units on the same list. The distance separating each switch and unit and each pair of units is calculated. The pair with the least separation distance is then identified. The decision to assign an unassigned extension switch to a unit, or to add a unit to a switch that has been previously assigned to a location, is made based upon the separation distance.

Essentially, if a unit is located within the distance that a previously assigned switch can extend a junction box (300 meters), then the unit will be assigned to that switch. Similarly, if two units are located such that one switch can extend a junction box to each of them (no more than 600 meters separating them), then they will be assigned to one switch. After each switch assignment by the Priority-Assignment actor, a copy of the domain-workspace blackboard is made by the Domain-Workspace-Record actor. The complete statement of the set of rules used by the Priority-Assignment actor to make extension switch assignments is found in Appendix D.

General-Assignment Actor. The General-Assignment actor operations are decided by the presence or absence of entries in three attributes as shown in Table II. The purpose of operation 1, add unassigned units to unit-priority-pair-list, is simply to clear the unassigned-units attribute and reduce the number of possible operations.

Table II. General-Assignment Actor Operations

Blackboard Attribute	Operation 1	2	3
unit-priority-pairs	x	x	1
unassigned-units	1	0	0
impossible-to-assign-units	x	1	0

0 ==> No entries for attribute (value nil)
1 ==> At least one entry (value not nil)
x ==> Attribute is irrelevant (don't care value)

1 : Add unassigned-units entries to unit-priority-pairs entries
2 : Request user assistance
3 : Assign units to switches

If any entries are in the impossible-to-assign-units attribute, then there are more units that require communications support than can be supported by the equipment available to the supporting signal unit, and the second operation, request user assistance, is performed. The user must decide to either ignore all units that cannot be supported and continue the design session, or terminate the current design session and change the type of supporting signal unit or its composition. The User-Input actor is invoked to request the user's decision.

The third operation, assign units to switches, is performed by identifying the highest priority unit currently not assigned. If more than one unit has the same priority, the first unit on the list is arbitrarily chosen. The distance between the chosen unit and each assigned extension switch is calculated. If the closest switch to the chosen unit has sufficient capacity available, the unit is assigned to that switch. If the switch can handle only part of the unit's terminal capacity, a partial assignment is made and the operation is continued with the next closest switch. If the nearest switch has no available capacity, the operation is repeated with the next closest switch.

Nodal-Assignment Actor. The Nodal-Assignment actor performs one of two operations, dependent upon whether or not there are any entries present in the assigned-extension-switches attribute of the domain-workspace blackboard. If there are any entries in that attribute, then extension switches exist that have not been assigned to a node-central and the operation performed by the Nodal-Assignment actor is to attempt to assign an unassigned extension switch to a node central. If there are no entries in the assigned-extension-switch attribute, then a backbone communications network is formed between the node central locations.

The process of assigning an extension switch to a node central is performed in a manner similar to that used to assign units to extension switches. If there are any node centrals that have not been assigned to a location, each of the extension switches that has not been assigned to a node central is paired off with each of the other unassigned extension switches. Then, each of the unassigned extension switches is paired off with each of the node centrals that has been assigned to a location. Otherwise, the only pairs that are formed are those involving the unassigned extension nodes and the node centrals that have been assigned to a location. Small extension switches are each assigned to one node central. Large extension switches, however, are provided access to two node centrals.

The distances between each of the objects in the pairs is calculated and the pair with the least separation is selected. An extension switch can be assigned to a node central if the separation distance is less than the planning radius of the MSE line-of-sight radio equipment, 25 kilometers, and if the node central has the capacity to add another extension switch. (The node central capacity defined within MSENDS-P is five extension switches.) Similarly, a node central that has not yet been placed at an initial location can be assigned to serve two extension switches separated by not more than 50 kilometers.

A heuristic technique is used to select node central locations. An initial location for a node central is selected half way between two extension switches that are separated by less than 50 kilometers. Any extension switches that are assigned to a node central after it is placed in its initial location must be located no further from that node central than 25 kilometers. Following the addition of an extension switch to a node central, the location of the node central is changed so that the new location is half way between the assigned switch and the previous location of the node central. This movement technique is used in an attempt to place each node central in a location approximately in the geographic center of the set of extension switches that are connected to it. A complete statement of the set of rules used by the Nodal-Assignment actor to select node central locations is found in Appendix D.

The formation of the backbone network is accomplished by first calculating the distance between each node central and all other node centrals. The closest pair is then identified, and if the distance is less than 25 kilometers, the two node centrals are connected. Each node central has the capability to connect to four other node centrals. Thus, if there are four or less node centrals, the backbone connection process continues until each node is connected to all other nodes that are within 25 kilometers. If there are more than four node centrals, the backbone connection process continues until each node central is either connected to the four closest nodes within 25 kilometers, or the only connections possible are to node centrals more than 25 kilometers away. A complete statement of the set of rules used by the Nodal-Assignment actor to create the backbone communications network is found in Appendix D.

Switch-Evaluation Actor. The evaluation performed by the Switch-Evaluation actor determines if the switch locations selected for a proposed system design meet relative location constraints. Specifically, the distance between each extension switch and every other extension switch is calculated. Any pair of switches that are within 300 meters--the distance a switch can extend a junction box--of each other are evaluated to determine if both switches are required at that location, or if one of the two switches can be released for use at another location.

The evaluation of any identified extension switch pairs begins by first determining which of the two switches was assigned first. The first switch assigned will be the switch that will be retained. Two consolidation strategies are available to the Switch-Evaluation actor. If the distance separating the two switches is less than 100 meters, then an attempt is made to consolidate communications support at the location of the retained switch. If the distance is greater than or equal to 100 meters, but less than 300 meters, then an attempt is made to provide support from both the retained switch at its original location and a junction box extended from the retained switch to the location at which the released switch had originally been located.

For either strategy, a check is first made to see if the retained switch has any junction boxes previously extended. If so, any units supported by the extended junction boxes remain assigned to the retained switch. Next, the terminal capacity required to support all units located within 100 meters of either switch is determined. If the total capacity required is less than the maximum capacity of the switch to be retained, then the second switch is released. Those units that are located within the area checked are assigned to the retained switch. Any units that belonged to either switch that are outside the area checked revert to an unassigned status.

After the units that will be supported by the retained switch are determined, the domain workspace record of the retained switch is used to reinstantiate the state of system as it was immediately following the original assignment of that switch by the Priority-Assignment actor. The original state is then adjusted to account for those units that were assigned to the retained switch from the released switch. Following state reinstantiation and adjustment, MSENDS-P transitions back to the initial-design context and starts the network redesign using the information placed on the domain-workspace blackboard that reflects the network adjustments.

If the the Switch-Evaluation actor determines that all relative location constraints are satisfied, the completed network is proposed to the system user, and MSENDS-P terminates its operations.

V. Implemented System Results

The prototype Mobile Subscriber Equipment Network Design System (MSENDS-P) described in the preceeding chapter was implemented and tested using a set of unit locations for a division size combat force. The network design that was proposed by MSENDS-P for the supplied set of locations is presented in the following pages. In addition, the network design proposed by MSENDS-P is compared to a second network design, proposed by a system that implements a modified form of the Schneider/Zastrow algorithm (32), for the same set of unit locations.

The set of unit locations for which the proposed communications networks were designed was obtained from the United States Army Signal Center, Fort Gordon, Georgia. The locations were originally generated for a logistical exercise, and thus represent a realistic deployment of the subordinate units of a combat division. The unit locations are included in the network design proposals produced by each system.

MSENDS-P Network Design Proposals

System Implementation. Two versions of the prototype Mobile Subscriber Equipment Network Design System were implemented. The two versions were essentially identical, differing only in the manner in which the Priority-Assignment actor in each version selected pairs of objects with the least separation distance. As described below, the identification of the closest pair of objects is a critical operation that strongly affects both the selection of locations for extension switches and the assignment of units to extension switches.

In both versions, the Priority-Assignment actor performed the operations of pairing off unassigned units with other unassigned units and pairing off unassigned units with assigned extension switches in the manner described earlier. The distance between the two objects in each pair was calculated using simple geometric relationships. For either version, if two or more pairs had an equal separation distance and consisted of the same types of objects (both pairs contained either two units or one unit and one switch), then the first pair found was the pair that was selected.

The principle difference between the two version of MSENDS-P was in how object pairs with equal separation distances, but differing in the types of objects that made up the pair, were handled. The first version, designated MSENDS-PO, selected from the set of object pairs having equal separation distances the first pair consisting of two unit objects that was found. The second version, designated MSENDS-P1, selected the first object pair consisting of a unit and an extension switch that was found.

The significance of the manner in which object pairs were selected is most apparent when the separation distances are zero. In the case of four or more collocated units with equal communications priority, the first assignment action by either system would be to assign a switch to one of the six object pairs, each consisting of two units, formed from the four unassigned units. Following assignment of the initial switch, a set of three object pairs would be formed. Two of the pairs would consist of a unit and the initially assigned switch, while the third pair would be composed of two units. In MSENDS-PO, the pair consisting of the two units would be selected as the nearest pair and an extension switch would be assigned to that pair. This switch would be collocated with the initially assigned switch.

In MSENDS-P1, however, one of the two pairs consisting of the initially assigned switch and a unit would be selected as the nearest pair. In this case, assuming that the initially assigned extension switch had sufficient capacity to support an additional unit, the unit would be added to that switch. Selection of an object pair consisting of a unit and an extension switch in preference to an object pair consisting of two units thus reduces the possibility of assigning additional extension switches to locations that already have an extension switch assigned.

Implementation of the two versions of MSENDS-P enabled a comparison to be made between the manner in which the network design process progressed in each system. The implementation of the two versions also enabled the effectiveness of the redesign architecture and the use of a blackboard control structure to support non-chronological backtracking to be determined.

The progression of the network design process was monitored by having each implemented version of MSENDS-P display the network designs that were produced by each iteration of the design process before they were evaluated for constraint satisfaction. The effectiveness of the redesign architecture and the use of the blackboard control structure to support non-chronological backtracking was determined by comparing the final network designs produced by each system.

Results. It was found that MSENDS-P0 required nine iterations of the design/redesign process to produce a network design that satisfied evaluation constraints and could therefore be proposed to the system user. The initial design produced by MSENDS-PO is presented in Table III. The design produced following the sixth iteration of the design/redesign process is presented in Table IV. The final network design produced by MSENDS-PO, and the design that would be proposed to a system user, is presented in Table V. Abbreviated results for all nine iterations of MSENDS-PO are presented in Table VI.

MSENDS-P1 required only two iterations of the design/redesign process to produce a network design that could be proposed to a system user. The initial design produced by MSENDS-P1 is identical to the design produced by MSENDS-PO after the sixth iteration of the design/redesign process, presented in Table IV. Similarly, the final design produced by MSENDS-P1 is identical to the final design produced by MSENDS-PO, presented in Table V.

The amount of system time required to run each version of MSENDS-P is presented in table VII. This information was obtained using the UNIX "time" command (21:23-24).

Tables III through V consist of three parts each. Part "a" of each table contains each unit's location and the extension switch to which each unit is assigned. The "unit id" column lists the identification that was assigned to each subordinate unit by the user. The "unit location" column lists the location of each unit, providing the six digit grid coordinates that locate each unit to within 100 meters. The first three digits locate each unit to the right, or east, of the grid origin, while the second three digits locate each unit above, or to the north, of the grid origin. All of the unit locations are contained within a single 100,000 meter grid square.

The "unit comm pri" column lists the communications priority assigned to each unit by the user, and can be used to identify the type of each unit and the number of terminals possessed by each unit as follows:

Communications Priority	Unit Type	Number of Terminals
10	Company	3
20	Battalion Headquarters	9
30	Division Support Command	60
40	Brigade Headquarters	21
50	Division Headquarters	90

The "supporting switch(es)" column lists the extension switch or switches that provide each unit access to the communications network. Extension switches starting with "s" are small extension switches, having a capacity of 30 terminals. Extension switches starting with "l" are large extension switches with a capacity of 150 terminals.

The "unit/switch separation" column lists the distance, in meters, separating each unit and the switch to which it is assigned. The "weighted unit/switch separation" column contains a figure that was arrived at by multiplying the separation distance in meters by the communications priority of the unit and the number of terminals belonging to the unit supported by each switch.

The weighted separation figure for each unit provides a method to assess the cost of providing communications to a unit. Since the terminals that MSENDS-P deals with are connected by wire to each extension switch, the further a unit is located from a switch, the more time it will take to lay wire from the unit's location to the switch. The communications priority assigned to a unit relates to how long a unit can wait to be provided with access to the communications network.

Units with low priorities can wait longer than units with high priorities. Thus, it "costs" more to install each circuit for units with a high communications priority than it does for units with a low communications priority.

The cost of extending a junction box from an extension switch to a supported unit was also calculated using the method described above. From a supported unit's point of view, having a junction box at their location is equivalent to having an extension switch at their location and MSENDS-P was therefore designed to provide junction box support to units where possible. From a system point of view, however, there is still a cost associated with extending a junction box, since it is connected by cable to the extension switch.

The value for "Total weighted separation" is the sum of each of the individual weighted separations calculated for each unit. The "Total separation" value is the sum of the individual distances separating each unit and switch. The "Total separation" value is not weighted to reflect the number of supported circuits.

Part "b" of each table contains the locations selected for each of the extension switches and the node central, or node centrals, to which each switch is connected. The locations in the "switch location" column are presented in the same manner as described for the units. The entries in the "type switch" column are self explanatory. The entries in the "supporting node-central(s)" column reflect the node central, entries starting with "n," to which each switch is connected. A blank entry indicates that a switch is not connected to any node central.

The "n-c/switch separation" column lists the distance, in meters, separating each switch from its supporting node central. Since line-of-sight radio is the connection medium, and terrain dependent connectivity evaluation is not performed by MSENDS-P, no attempt to attach any costs to the separation distances is made.

The information presented in part "c" of each table includes the location that was selected for each node central, and the connections between node centrals, listed in the "backbone connections" column, that were made to establish the backbone communications network. The distances separating each of the node centrals that are connected to form the backbone network are presented, but, as with the extension switch to node central connections, no attempt to attach any costs to the separation distances is made.

AD-A163 994 A KNOWLEDGE BASED SYSTEM FOR THE DESIGN OF MOBILE 2/2
SUBSCRIBER EQUIPMENT CO..(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. B A TOLLIFFE
UNCLASSIFIED DEC 85 AFIT/GCS/ENG/85D-16 F/G 17/2 NL

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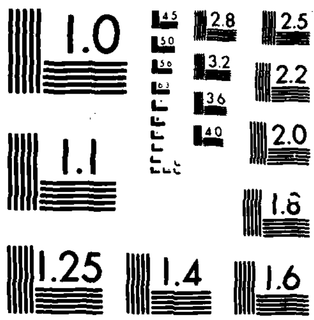
1.0
2.8
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2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Table III.

Initial Design Produced by MSENDS-PO

(a) Unit Locations and Extension Switch Assignments

unit id	unit location	unit comm pri	supporting switch(es)	unit/switch separation	weighted unit/switch separation
b/40 s&t	185 643	10	s00016	282.843	8485.281
a/40 s&t	203 667	10	s00016	2973.214	89196.412
spt/40 med	189 636	10	s00015	0.000	0.000
c/40 med	300 744	10	s00023	9600.521	288015.625
b/40 med	307 688	10	s00010	12055.289	361658.679
a/40 med	238 813	10	s00023	4263.801	127914.034
f/40 maint	188 637	10	s00015	141.421	4242.641
e/40 maint	209 677	10	s00016	4123.106	123693.169
d/40 maint	299 745	10	s00010	7507.330	225219.893
c/40 maint	307 688	10	s00009	8143.709	244311.277
b/40 maint	234 814	10	s00023	4104.875	123146.255
a/40 maint	188 637	10	s00015	141.421	4242.641
40 ag	161 624	10	s00024	1526.434	45793.013
40 nbc	257 726	10	s00023	7093.659	212809.774
40 mp co	139 728	10	100008	824.621	24738.634
c/40 cewi	137 736	10	100008	0.000	0.000
b/40 cewi	137 736	10	100008	0.000	0.000
a/40 cewi	137 736	10	100008	0.000	0.000
hc 40 cewi	137 736	10	100008	0.000	0.000
e/40 engr	526 846	10	s00020	9126.883	273806.501
d/40 engr	167 713	10	s00022	0.000	0.000
c/40 engr	365 731	10	s00009	3920.459	117613.775
b/40 engr	447 738	10	s00020	5903.389	177101.666
a/40 engr	464 856	10	s00020	6087.693	182630.775
hc 40 engr	167 713	10	s00022	0.000	0.000
e/40 cbt avn	174 616	10	s00024	0.000	0.000
d/40 cbt avn	174 616	10	s00024	0.000	0.000
c/40 cbt avn	174 616	10	s00024	0.000	0.000
b/40 cbt avn	306 689	10	s00009	8095.678	242870.336
a/40 cbt avn	232 615	10	s00015	4785.394	143561.833
hc 40 cbt avn	174 616	10	s00024	0.000	0.000
hb 2/441 ada	211 780	10	s00023	0.000	0.000
hb 2/43 arty	399 867	10	s00019	0.000	0.000
hb 2/42 arty	416 813	10	s00021	0.000	0.000
hb 2/41 arty	449 797	10	s00020	0.000	0.000
hb 2/40 arty	410 891	10	s00018	0.000	0.000
40 tab	349 801	10	s00010	0.000	0.000

Table III.

Initial Design Produced by MSENDS-PO

(a) Unit Locations and Extension Switch Assignments (continued)

unit id	unit location	unit comm pri	supporting switch(es)	unit/switch separation	weighted unit/switch separation
hq 40 s&t bn	183 645	20	s00016	0.000	0.000
hq 40 med bn	189 636	20	s00015	0.000	0.000
hq 40 maint bn	188 637	20	s00015	141.421	25455.844
hq 40 cewi bn	137 736	20	100008	0.000	0.000
hq 40 engr bn	167 713	20	s00022	0.000	0.000
hq 40 cbt avn bn	174 616	20	s00017	0.000	0.000
hq 2/441 ada bn	211 780	20	s00023	0.000	0.000
hq 2/43 arty bn	399 867	20	s00019	0.000	0.000
hq 2/42 arty bn	416 813	20	s00021	0.000	0.000
hq 2/41 arty bn	449 797	20	s00020	0.000	0.000
hq 2/40 arty bn	410 891	20	s00018	0.000	0.000
hhc 40th discom	163 622	30	s00014	0.000	0.000
			s00013	0.000	0.000
hhb 40th divarty	349 801	40	s00010	0.000	0.000
hhc 3d bde	341 762	40	s00009	0.000	0.000
hhc 2d bde	397 777	40	s00011	0.000	0.000
hhc 1st bde	366 860	40	s00012	0.000	0.000
hhc 40th inf-div	137 736	50	100008	0.000	0.000

Total separation = 100843.162
Total weighted separation = 3046508.055

Table III.

Initial Design Produced by MSENDS-PO

(b) Extension Switch Locations and Node Central Assignments

switch id	switch location	type switch	supporting node-central(s)	n-c/switch separation
100008	137 736	large-extension-switch	n00005	16178.999
			n00006	4652.956
s00024	174 616	small-extension-switch	n00004	0.000
s00023	211 780	small-extension-switch	n00006	4640.043
s00022	167 713	small-extension-switch	n00006	3400.000
s00021	416 813	small-extension-switch	n00007	1843.909
s00020	449 797	small-extension-switch	*	
s00019	399 867	small-extension-switch	n00007	5800.862
s00018	410 891	small-extension-switch	n00007	8287.340
s00017	174 616	small-extension-switch	n00004	0.000
s00016	183 645	small-extension-switch	n00006	9800.000
s00015	189 636	small-extension-switch	n00006	10716.809
s00014	163 622	small-extension-switch	n00005	19235.384
s00013	163 622	small-extension-switch	n00005	19235.384
s00012	366 860	small-extension-switch	n00007	6020.797
s00011	397 777	small-extension-switch	n00007	3201.562
s00010	349 801	small-extension-switch	n00005	6621.933
s00009	341 762	small-extension-switch	n00005	4404.543

* No connection made. Node centrals within range have no available capacity.

(c) Node Central Locations and Backbone Network Assignments

node-central	node location	backbone connections	n-c/n-c separation
n00007	398 809	n00006	22490.220
		n00005	11225.863
n00006	183 743	n00004	12731.850
		n00005	11526.057
		n00007	22490.220
n00005	297 760	n00004	18938.057
		n00006	11526.057
		n00007	11225.863
n00004	174 616	n00005	18938.057
		n00006	12731.850

Table IV.

Design Produced by MSENDS-P0 following iteration 6
and
Initial Design Produced by MSENDS-P1

(a) Unit Locations and Extension Switch Assignments

unit id	unit location	unit comm pri	supporting switch(es)	unit/switch separation	weighted unit/switch separation
b/40 s&t	185 643	10	s00016	282.843	8485.281
a/40 s&t	203 667	10	s00Q16	2973.214	89196.412
spt/40 med	189 636	10	s00015	0.000	0.000
c/40 med	300 744	10	s00023	9600.521	288015.625
b/40 med	307 688	10	s00010	12055.289	361658.679
a/40 med	238 813	10	s00023	4263.801	127914.034
f/40 maint	188 637	10	s00024	0.000	0.000
e/40 maint	209 677	10	s00016	4123.106	123693.169
d/40 maint	299 745	10	s00010	7507.330	225219.893
c/40 maint	307 688	10	s00009	8143.709	244311.277
b/40 maint	234 814	10	s00023	4104.875	123146.255
a/40 maint	188 637	10	s00024	0.000	0.000
40 ag	161 624	10	s00017	1526.434	45793.013
40 nbc	257 726	10	s00023	7093.659	212809.774
40 mp co	139 728	10	100008	824.621	24738.634
c/40 cewi	137 736	10	100008	0.000	0.000
b/40 cewi	137 736	10	100008	0.000	0.000
a/40 cewi	137 736	10	100008	0.000	0.000
hc 40 cewi	137 736	10	100008	0.000	0.000
e/40 engr	526 846	10	s00020	9126.883	273806.501
d/40 engr	167 713	10	s00022	0.000	0.000
c/40 engr	365 731	10	s00009	3920.459	117613.775
bb/40 engr	447 738	10	s00020	5903.389	177101.666
a/40 engr	464 856	10	s00020	6087.693	182630.775
hc 40 engr	167 713	10	s00022	0.000	0.000
e/40 cbt avn	174 616	10	s00017	0.000	0.000
d/40 cbt avn	174 616	10	s00017	0.000	0.000
c/40 cbt avn	174 616	10	s00017	0.000	0.000
b/40 cbt avn	306 689	10	s00009	8095.678	242870.336
a/40 cbt avn	232 615	10	s00015	4785.394	143561.833
hc 40 cbt avn	174 616	10	s00017	0.000	0.000
hb 2/441 ada	211 780	10	s00023	0.000	0.000
hb 2/43 arty	399 867	10	s00019	0.000	0.000
hb 2/42 arty	416 813	10	s00021	0.000	0.000
hb 2/41 arty	449 797	10	s00020	0.000	0.000
hb 2/40 arty	410 891	10	s00018	0.000	0.000
40 tab	349 801	10	s00010	0.000	0.000

Table IV.

Design Produced by MSENDS-PO following iteration 6
and
Initial Design Produced by MSENDS-P1

(a) Unit Locations and Extension Switch Assignments (continued)

unit id	unit location	unit comm pri	supporting switch(es)	unit/switch separation	weighted unit/switch separation
hq 40 s&t bn	183 645	20	s00016	0.000	0.000
hq 40 med bn	189 636	20	s00015	0.000	0.000
hq 40 maint bn	188 637	20	s00015	141.421	25455.844
hq 40 cewi bn	137 736	20	100008	0.000	0.000
hq 40 engr bn	167 713	20	s00022	0.000	0.000
hq 40 cbt avn bn	174 616	20	s00017	0.000	0.000
hq 2/441 ada bn	211 780	20	s00023	0.000	0.000
hq 2/43 arty bn	399 867	20	s00019	0.000	0.000
hq 2/42 arty bn	416 813	20	s00021	0.000	0.000
hq 2/41 arty bn	449 797	20	s00020	0.000	0.000
hq 2/40 arty bn	410 891	20	s00018	0.000	0.000
hhc 40th discom	163 622	30	s00014	0.000	0.000
			s00013	0.000	0.000
hhb 40th divarty	349 801	40	s00010	0.000	0.000
hhc 3dbde	341 762	40	s00009	0.000	0.000
hhc 2d bde	397 777	40	s00011	0.000	0.000
hhc 1st bde	366 860	40	s00012	0.000	0.000
hhc 40th inf-div	137 736	50	100008	0.000	0.000

Total separation = 100560.319
Total weighted separation = 3038022.774

Table IV.

Design Produced by MSENDS-PO following iteration 6
and
Initial Design Produced by MSENDS-P1

(b) Extension Switch Locations and Node Central Assignments

switch id	switch location	type switch	supporting node-central(s)	n-c/switch separation
100008	137 736	large-extension-switch	n00004	4472.136
			n00005	3551.056
s00024	188 637	small-extension-switch	n00005	7605.919
s00023	211 780	small-extension-switch	n00004	6003.332
s00022	167 713	small-extension-switch	n00005	1303.840
s00021	416 813	small-extension-switch	n00007	6466.065
s00020	449 797	small-extension-switch	n00007	8982.205
s00019	399 867	small-extension-switch	n00006	1414.214
s00018	410 891	small-extension-switch	n00006	3330.165
s00017	174 616	small-extension-switch	n00004	11221.854
s00016	183 645	small-extension-switch	n00005	6670.832
s00015	189 636	small-extension-switch	n00005	7738.863
s00014	163 622	small-extension-switch	n00004	10751.744
s00013	163 622	small-extension-switch	n00004	10751.744
s00012	366 860	small-extension-switch	n00006	2102.380
s00011	397 777	small-extension-switch	n00007	3605.551
s00010	349 801	small-extension-switch	n00007	2505.993
s00009	341.762	small-extension-switch	n00007	2624.881

(c) Node Central Locations and Backbone Network Assignments

node-central	node location	backbone connections	n-c/n-c separation
n00007	361 779	n00005	21760.974
		n00004	18708.554
		n00006	9314.505
n00006	385 869	n00004	24798.589
		n00007	9314.505
n00005	156 706	n00004	3330.165
		n00007	21760.974
n00004	181 728	n00005	3330.165
		n00006	24798.589
		n00007	18708.554

Table V.

Final Design Proposed by MSENDS-P0 and MSENDS-P1

(a) Unit Locations and Extension Switch Assignments

unit id	unit location	unit comm pri	supporting switch(es)	unit/switch separation	weighted unit/switch separation
b/40 s&t	185 643	10	s00016	282.843	8485.281
a/40 s&t	203 667	10	s00016	2973.214	89196.412
spt/40 med	189 636	10	s00015	0.000	0.000
c/40 med	300 744	10	s00009	4477.723	134331.679
b/40 med	307 688	10	s00024	0.000	0.000
a/40 med	238 813	10	s00023	4263.801	127914.034
f/40 maint	188 637	10	s00015	141.421	4242.641
e/40 maint	209 677	10	s00016	4123.106	123693.169
d/40 maint	299 745	10	s00009	4531.004	135930.129
c/40 maint	307 688	10	s00024	0.000	0.000
b/40 maint	234 814	10	s00023	4104.875	123146.255
a/40 maint	188 637	10	s00015	141.421	4242.641
40 ag	161 624	10	s00017	1526.434	45793.013
40 nbc	257 726	10	s00024	6280.127	188403.822
40 mp co	139 728	10	100008	824.621	24738.634
c/40 cewi	137 736	10	100008	0.000	0.000
b/40 cewi	137 736	10	100008	0.000	0.000
a/40 cewi	137 736	10	100008	0.000	0.000
hc 40 cewi	137 736	10	100008	0.000	0.000
e/40 engr	526 846	10	s00020	9126.883	273806.501
d/40 engr	167 713	10	s00022	0.000	0.000
c/40 engr	365 731	10	s00009	3920.459	117613.775
b/40 engr	447 738	10	s00020	5903.389	177101.666
a/40 engr	464 856	10	s00020	6087.693	182630.775
hc 40 engr	167 713	10	s00022	0.000	0.000
e/40 cbt avn	174 616	10	s00017	0.000	0.000
d/40 cbt avn	174 616	10	s00017	0.000	0.000
c/40 cbt avn	174 616	10	s00017	0.000	0.000
b/40 cbt avn	306 689	10	s00024	141.421	4242.641
a/40 cbt avn	232 615	10	s00015	4785.394	143561.833
hc 40 cbt avn	174 616	10	s00017	0.000	0.000
hb 2/441 ada	211 780	10	s00023	0.000	0.000
hb 2/43 arty	399 867	10	s00019	0.000	0.000
hb 2/42 arty	416 813	10	s00021	0.000	0.000
hb 2/41 arty	449 797	10	s00020	0.000	0.000
hb 2/40 arty	410 891	10	s00018	0.000	0.000
40 tab	349 801	10	s00010	0.000	0.000

Table V.

Final Design Proposed by MSENDS-P0 and MSENDS-P1

(a) Unit Locations and Extension Switch Assignments (continued)

unit id	unit location	unit comm pri	supporting switch(es)	unit/switch separation	weighted unit/switch separation
hq 40 s&t bn	183 645	20	s00016	0.000	0.000
hq 40 med bn	189 636	20	s00015	0.000	0.000
hq 40 maint bn	188 637	20	s00015	141.421	25455.844
hq 40 cewi bn	137 736	20	100008	0.000	0.000
hq 40 engr bn	167 713	20	s00022	0.000	0.000
hq 40 cbt avn bn	174 616	20	s00017	0.000	0.000
hq 2/441 ada bn	211 780	20	s00023	0.000	0.000
hq 2/43 arty bn	399 867	20	s00019	0.000	0.000
hq 2/42 arty bn	416 813	20	s00021	0.000	0.000
hq 2/41 arty bn	449 797	20	s00020	0.000	0.000
hq 2/40 arty bn	410 891	20	s00018	0.000	0.000
hhc 40th discom	163 622	30	s00014	0.000	0.000
			s00013	0.000	0.000
hhb 40th divarty	349 801	40	s00010	0.000	0.000
hhc 3d bde	341 762	40	s00009	0.000	0.000
hhc 2d bde	397 777	40	s00011	0.000	0.000
hhc 1st bde	366 860	40	s00012	0.000	0.000
hhc 40th inf-div	137 736	50	100008	0.000	0.000

Total separation = 63777.251
Total weighted separation = 1934530.743

Table V.

Final Design Proposed by MSENDS-P0 and MSENDS-P1

(b) Extension Switch Locations and Node Central Assignments

switch id	switch location	type switch	supporting node-central(s)	n-c/switch separation
100008	137 736	large-extension-switch	n00004	10667.708
			n00005	4652.956
s00024	307 688	small-extension-switch	n00004	7823.043
s00023	211 780	small-extension-switch	n00005	4640.043
s00022	167 713	small-extension-switch	n00005	3400.000
s00021	416 813	small-extension-switch	n00007	6466.065
s00020	449 797	small-extension-switch	n00007	8982.205
s00019	399 867	small-extension-switch	n00006	1414.214
s00018	410 891	small-extension-switch	n00006	3330.165
s00017	174 616	small-extension-switch	n00004	8591.275
s00016	183 645	small-extension-switch	n00005	9800.000
s00015	189 636	small-extension-switch	n00005	10716.809
s00014	163 622	small-extension-switch	n00004	8919.641
s00013	163 622	small-extension-switch	n00004	8919.641
s00012	366 860	small-extension-switch	n00006	2102.380
s00011	397 777	small-extension-switch	n00007	3605.551
s00010	349 801	small-extension-switch	n00007	2505.993
s00009	341 762	small-extension-switch	n00007	2624.881

(c) Node Central Locations and Backbone Network Assignments

node-central	node location	backbone connections	n-c/n-c separation
n00007	361 779	n00005	18160.396
		n00004	16380.781
		n00006	9314.505
n00006	385 869	n00004	24352.618
		n00005	23807.562
		n00007	9314.505
n00005	183 743	n00004	7640.026
		n00006	23807.562
		n00007	18160.396
n00004	229 682	n00005	7640.026
		n00006	24352.618
		n00007	16380.781

Table VI.

Consolidated Results of MSENDS-PO

Results of iteration number 1:

Total separation = 100843.162
Total weighted separation = 3046508.055

Results of iteration number 2:

Total separation = 100843.162
Total weighted separation = 3046508.055

Results of iteration number 3:

Total separation = 100843.162
Total weighted separation = 3046508.055

Results of iteration number 4:

Total separation = 100843.162
Total weighted separation = 3046508.055

Results of iteration number 5:

Total separation = 100843.162
Total weighted separation = 3046508.055

Results of iteration number 6:

Total separation = 100560.319
Total weighted separation = 3038022.774

Results of iteration number 7:

Total separation = 100843.162
Total weighted separation = 3046508.055

Results of iteration number 8:

Total separation = 100843.162
Total weighted separation = 3046508.055

Results of iteration number 9:

Total separation = 63777.251
Total weighted separation = 1934530.743

Table VII.

System Time Required to Run MSENDS-P

Version	System Time
MSENDS-P0	562.7
MSENDS-P1	650.6

Schneider/Zastrow Network Design Proposal

A second system that implemented a modified version of the Schneider/Zastrow algorithm was used to generate a network design with the same set of unit locations supplied to MSENDS-P. This network was generated for the purpose of comparing a network design produced by a system using specialized domain knowledge, MSENDS-P, to a design produced by a system using a generalized design technique. This second system was also implemented in ROSS.

One major modification made to the Schneider/Zastrow algorithm, as presented in (32), was the elimination of the use of a maximum clustering distance. The imposition of a maximum allowable separation distance would be possible if an unlimited number of extension switches were available (32:3). However, since the number of available extension switches is fixed for a given type of signal unit, the establishment of a maximum clustering distance is not reasonable.

A second major modification to the algorithm was to perform only one level of clustering. This was done because no cost was attached to line-of-sight radio links in MSENDS-P, and the only connections for which a cost comparison could be made were those at the first level of concentration, the connection of units to extension switches. The method used to determine a cost for these connections is the same as was described earlier.

The final modification was to immediately assign the large extension switch to the division headquarters, two small extension switches to the division support command, and one small extension switch to each of the brigade headquarters units. This was done because each of these units has a number of terminals greater than half the available capacity of a small extension switch. This modification eliminates any need to determine how to assign a switch to a pair of units that together have more terminals requiring support than a single switch can handle.

The network design produced by the modified implementation of the Schneider/Zastrow algorithm is presented in Table VIII. The amount of system time, obtained by using the UNIX "time" command (21:23-24), is also presented in Table VIII. The description of the type of information contained in Tables III through V presented earlier for MSENDS-P applies to the information presented in Table VIII as well.

Table VIII.

Network Design Produced By Schneider/Zastrow Algorithm

(a) Unit Locations and Extension Switch Assignments

unit id	unit location	unit comm pri	supporting switch(es)	unit/switch separation	weighted unit/switch separation
b/40 s&t	185 643	10	s00012	141.421	4242.641
a/40 s&t	203 667	10	s00012	3023.243	90697.299
spt/40 med	189 636	10	s00009	1044.031	31320.920
c/40 med	300 744	10	s00018	3640.055	109201.648
b/40 med	307 688	10	s00013	1664.332	49929.951
a/40 med	238 813	10	s00008	3047.950	91438.504
f/40 maint	188 637	10	s00012	538.516	16155.494
e/40 maint	209 677	10	s00009	3929.377	117881.296
d/40 maint	299 745	10	s00018	3710.795	111323.852
c/40 maint	307 688	10	s00013	1664.332	49929.951
b/40 maint	234 814	10	s00008	2884.441	86533.231
a/40 maint	188 637	10	s00012	538.516	16155.494
40 ag	161 624	10	s00010	1303.840	39115.214
40 nbc	257 726	10	s00013	4622.770	138683.092
40 mp co	139 728	10	100020	728.011	21840.330
c/40 cewi	137 736	10	100020	100.000	3000.000
b/40 cewi	137 736	10	100020	100.000	3000.000
a/40 cewi	137 736	10	100020	100.000	3000.000
hc 40 cewi	137 736	10	100020	100.000	3000.000
e/40 engr	526 846	10	s00005	8261.961	247858.831
d/40 engr	167 713	10	s00011	0.000	0.000
c/40 engr	365 731	10	s00018	3780.212	113406.349
b/40 engr	447 738	10	s00005	5869.412	176082.367
a/40 engr	464 856	10	s00004	5215.362	156460.858
hc 40 engr	167 713	10	s00011	0.000	0.000
e/40 cbt avn	174 616	10	s00010	223.607	6708.204
d/40 cbt avn	174 616	10	s00010	223.607	6708.204
c/40 cbt avn	174 616	10	s00010	223.607	6708.204
b/40 cbt avn	306 689	10	s00013	1526.434	45793.013
a/40 cbt avn	232 615	10	s00009	4080.441	122413.235
hc 40 cbt avn	174 616	10	s00010	223.607	6708.204
hb 2/441 ada	211 780	10	s00008	1220.656	36619.667
hb 2/43 arty	399 867	10	s00007	0.000	0.000
hb 2/42 arty	416 813	10	s00006	0.000	0.000
hb 2/41 arty	449 797	10	s00005	1216.553	36496.575
hb 2/40 arty	410 891	10	s00004	1220.656	36619.667
40 tab	349 801	10	s00019	0.000	0.000

Table VIII.

Network Design Produced By Schneider/Zastrow Algorithm

(a) Unit Locations and Extension Switch Assignments (continued)

unit id	unit location	unit comm pri	supporting switch(es)	unit/switch separation	weighted unit/switch separation
hq 40 s&t bn	183 645	20	s00012	424.264	76367.532
hq 40 med bn	189 636	20	s00009	1044.031	187925.517
hq 40 maint bn	188 637	20	s00012	538.516	96932.967
hq 40 cewi bn	137 736	20	100020	100.000	18000.000
hq 40 engr bn	167 713	20	s00011	0.000	0.000
hq 40 cbt avn bn	174 616	20	s00010	223.607	40249.224
hq 2/441 ada bn	211 780	20	s00008	1220.656	219718.001
hq 2/43 arty bn	399 867	20	s00007	0.000	0.000
hq 2/42 arty bn	416 813	20	s00006	0.000	0.000
hq 2/41 arty bn	449 797	20	s00005	1216.553	218979.451
hq 2/40 arty bn	410 891	20	s00004	1220.656	219718.001
hhc 40th discom	163 622	30	s00014	0.000	0.000
			s00015	0.000	0.000
hhb 40th divarty	349 801	40	s00019	0.000	0.000
hhc 3d bde	341 762	40	s00018	1000.000	840000.000
hhc 2d bde	397 777	40	s00017	0.000	0.000
hhc 1st bde	366 860	40	s00016	0.000	0.000
hhc 40th inf-div	137 736	50	100020	100.000	450000.000

Total separation = 73256.025
Total weighted separation = 4352922.986

Amount of System Time Required = 303.5

Table VIII.

Network Design Produced By Schneider/Zastrow Algorithm

(b) Extension Switch Locations

switch id	switch location	type switch
100020	137 735	large-extension-switch
s00019	349 801	small-extension-switch
s00018	335 754	small-extension-switch
s00017	397 777	small-extension-switch
s00016	366 860	small-extension-switch
s00015	163 622	small-extension-switch
s00014	163 622	small-extension-switch
s00013	293 697	small-extension-switch
s00012	186 642	small-extension-switch
s00011	167 713	small-extension-switch
s00010	172 617	small-extension-switch
s00009	199 639	small-extension-switch
s00008	218 790	small-extension-switch
s00007	399 867	small-extension-switch
s00006	416 813	small-extension-switch
s00005	461 795	small-extension-switch
s00004	420 884	small-extension-switch

Discussion, Comparison, and Interpretation of Results

From the results presented in Table VI, it can be seen that the design progression for MSENDS-PO does not yield consistently lower weighted costs. This is a result of the manner in which constraint evaluations are performed.

As described earlier, the Switch-Evaluation actor calculates the separation distances between each possible pair of switches and attempts to consolidate any switches found to be separated by a distance of less than 300 meters. The first pair of switches identified with a separation less than 300 meters is the pair for which consolidation is performed. The consolidation of a pair of switches is accomplished by reinstantiating the system state as it was at the time of the assignment of the first switch in the pair. Therefore, if a consolidation is performed for a pair of switches in which the first extension switch was assigned late in the design process, the affect of that consolidation can be negated if a second consolidation is performed for a switch that was assigned early in the design process.

The most obvious instance in which the negation of a previous consolidation occurs in MSENDS-PO is in iteration 7 (Table VI). In this instance, the consolidation of switches s00024 and s00015 (Table IVb) resulted in the negation of the consolidations made by iterations 1 through 6.

The selection method used by the Priority-Assignment actor of MSENDS-P1 results in the reduction of redundant switch assignments, and thus, for the particular set of unit locations used, an elimination of the consolidation negation problem. The use of the redesign process by

MSENDS-PO, however, is able to compensate for the problem of consolidation negation and produce an identical design to that produced by MSENDS-P1. Thus, based solely upon the number of redesign iterations, MSENDS-P1 may be considered more efficient than MSENDS-PO, since it requires fewer iterations and produces identical final results.

If, however, efficiency is considered solely as a factor of the amount of time required to produce a final result, then MSENDS-PO may be considered more efficient than MSENDS-P1, since it required less time to run (Table VII). The selection method used by the Priority-Assignment actor of MSENDS-PO assigns extension switches to locations faster than the method used by MSENDS-P1. For the particular set of unit locations used, the faster rate of extension switch assignment results in a reduction in the amount of time required to achieve a final solution.

The formation of object pairs by the Priority-Assignment actor is an operation that requires time $O(N^2)$, where N is the number of units having the same communications priority. As shown in Table I (page 72), the Priority-Assignment actor is invoked as long as there are extension switches that have not been assigned to a location. Because the Priority-Assignment actor in MSENDS-PO will select an object pair that contains two units and assign a switch to that pair, extension switches are assigned faster by MSENDS-PO than MSENDS-P1.

Once all extension switches have been assigned to a location, the General-Assignment actor is invoked. The General-Assignment actor requires time $O(M^2)$ to assign a unit to a switch where the value of M is the number of extension switches that exist within the system. Because MSENDS-P1 attempts to avoid making redundant switch assignments, its run-time is dependent upon the number of units that the system is handling while the run-time of MSENDS-P0 is influenced by the total number of switches within the system. In the case of the set of unit locations that was used, the largest number of units at one communications priority level is 37, while the total number of extension switches is 17.

For all nine iterations of MSENDS-P0, the Priority-Assignment actor was invoked 70 times, nine of which involved the 37 units with the same communications priority. MSENDS-P1, in only two iterations, invoked the Priority-Assignment actor 60 times, of which 35 involved the 37 units with the same communications priority. This difference in the number of times the pairing of the large number of units with the same priority level was performed is the cause of the difference in the amount of system run-time required by each version.

The apparent difference in efficiency between the two versions is a factor of the set of locations that was used. Because the General-Assignment actor is not invoked until all extension switches are assigned to a location, the time required by the Priority-Assignment actor will determine the overall time complexity for both versions of MSENDS-P. Both versions are therefore bounded by the same time requirement for the Priority-Assignment actor, $O(N^2)$.

A comparison of the total weighted separations for the final design proposed by MSENDS-P (Table V) and the design produced by the Schneider/Zastrow method (Table VIII) indicates that the use of domain knowledge by MSENDS-P enabled a design with a lower total cost to be produced. The total distance separating units and extension switches is also lower for the final design proposed by MSENDS-P than for the design proposed by the Schneider/Zastrow method.

The use of domain knowledge by MSENDS-P also resulted in a lower total weighted cost for each intermediate network design produced. However, it was not until the final design produced by MSENDS-P that the total separation distance was reduced to a level below that of the Schneider/Zastrow method.

The amount of system time required to produce a design using the Schneider/Zastrow algorithm was less than for either version of MSENDS-P. Since the Schneider/Zastrow algorithm uses object pairs in the same manner as does MSENDS-P, the same time requirement, $O(N^2)$ where N is the number of units, applies to the Schneider/Zastrow algorithm. The difference in the amount of run-time required is attributable to two factors. First, only one design iteration is gone through by the Schneider/Zastrow algorithm. Second, the implemented system does not continue clustering beyond the extension switch level. Thus, no conclusions can be drawn from a comparison of the run-times for the two versions of MSENDS-P and the system using the Schneider/Zastrow algorithm.

The use of only a single set of unit locations was influenced primarily by the lack of division size deployments dealing with units down to the company level. The generation of random unit locations is not a viable alternative. The relationships between units is an important factor in the distribution of units throughout the battlefield. Therefore, the use of one set of unit locations that strongly reflects the manner in which a division size force may be deployed is a much better case with which to attempt system validation than random location generation.

Based on the results produced by the prototype Mobile Subscriber Equipment Network Design Systems that were implemented, it is apparent that the effectiveness of existing methods to provide approximate solutions to the general network design problem can be improved upon by the use of domain knowledge in the design process. It is also apparent that the design, evaluate, redesign cycle used by the implemented systems is an effective way to use the domain knowledge available to the system.

The heuristic methods that were incorporated into the systems for the placement of supporting items of MSE system equipment were able to produce a system that supported those units having high communications priorities. It is thus concluded that the combination of heuristic methods to select locations for specific items of equipment with heuristic methods to solve the general network design problem has resulted in the implementation of a system that can begin to provide useful assistance in the design of tactical communications networks and that can be further developed to provide increased assistance.

VI. Conclusions and Recommendations

This project designed an expert system to assist tactical communications systems planners design communications networks. Portions of the designed system were implemented, combining network design heuristics with domain knowledge specific to the United States Army's Mobile Subscriber Equipment (MSE) communications system. The implemented system was tested by designing a terrain independent communications network for the units of a deployed division size combat force.

Conclusions

Based on the results produced by the implemented versions of the Mobile Subscriber Equipment Network Design System prototype (MSENDS-P), the following conclusions are drawn:

1. The effectiveness of existing methods to provide approximate solutions to the general network design problem is improved by the use of domain specific knowledge in the design process.
2. The design, evaluate, redesign architecture used by MSENDS-P is an effective way to use the domain knowledge available to the system.
3. Expert system technology can be used to provide assistance to personnel designing tactical communications networks.

Recommendations

The prototype network design system that this project implemented has shown that the use of expert system technology can produce a network design in a terrain independent environment. Because it is unlikely that a combat force will ever be in a situation in which terrain will not be an important factor, the following recommendations for further development of the Mobile Subscriber Equipment Network Design System are made.

The incorporation of terrain elevation data and knowledge sources for the evaluation of terrain dependent line of sight radio connectivity and prediction of locations between which line of sight connectivity can be established should be the next step in the development of MSENDS. The implementation of these knowledge sources should be made using techniques that have been proven effective by use in propagation prediction systems such as those described in Chapter II. Using techniques known to be effective will enable primary emphasis to be placed upon developing strategies that select sites for the relocation of equipment in the design revision phase of MSENDS. Following successful incorporation of line of sight radio propagation prediction techniques, the development of terrain feature evaluation specialists and the inclusion of descriptive digital terrain databases should be pursued.

The reason for recommending that propagation prediction be incorporated in MSENDS before terrain feature evaluation is based upon the fact that the acceptability of various terrain features will be dependent upon the the tactical situation in which a communications network is established. Thus, the development of terrain feature evaluation specialists should begin with features that are relatively independent of the tactical situation. The development of evaluation strategies that reflect the tactical situation should be pursued as the system matures.

Based upon the manner in which the different methods of selecting the closest object pair by the Priority-Assignment actor affected the run-time of the implemented versions of MSENDS-P, it is recommended that further research be performed on the way in which the initial terrain independent network is generated. In particular, for situations in which an essentially one-to-one correspondence between high priority units (units with a communications priority of 20 or greater) and available extension switches can be made, the direct assignment of extension switches to high priority units to form the initial network design should be investigated.

Both versions of MSENDS-P were implemented such that all user interactions with the system were performed at system start-up. The involvement of the user in the system operation as proposed in the design of MSENDS, and as discussed above, should be pursued. The use of the user as an evaluation specialist in the evaluation of terrain features as affected by the tactical situation is strongly recommended.

Appendix A:
Mobile Subscriber Equipment (MSE) System

The United States Army is currently in the process of purchasing new multichannel communications equipment. Although the specific equipment that will be purchased has not yet been determined, it has been decided that the equipment will be acquired using an off-the-shelf approach, and no funds will be spent for developmental research. The new equipment, known as Mobile Subscriber Equipment (MSE), will provide common user access to subscribers throughout the area of the battlefield. It is planned that fielding of the equipment will begin in the 1987-1988 time frame (22:18).

This appendix presents portions of the operational concept for the employment of the MSE system as developed by the United States Army Signal Center, Fort Gordon, Georgia. The material presented will provide a general overview of the MSE system with emphasis being given to those factors that have an impact on the design of the communications network. The information presented is taken from MSE working papers published by the United States Army Signal Center (36). An abbreviated version of the information presented in the MSE working papers is also available in (31).

The MSE System

The MSE system is a multichannel communications network for use at the division and corps level. The network is composed of primary nodes that form a backbone system and extension nodes and Radio Access Units (RAU) that provide users access to the system. The primary nodes are interconnected by multichannel radio links to form a grid system. Extension nodes and RAUs access the communications network by means of multichannel radio links connecting them to primary nodes.

The MSE system is designed to provide communications support as an integrated network at the corps and division level. For a corps force composed of five divisions, a total of 56 primary nodes will be available in the organic corps and division signal units to form the network backbone system. Each of the primary nodes in the backbone is generally connected to four other primary nodes to form the backbone grid. Extension nodes and RAUs are usually provided multichannel radio links to two of the primary nodes in the backbone system, with one link active while the other is in a standby condition to provide backup as needed.

Extension nodes provide access to the backbone network for static subscribers. Mobile subscribers are provided access to the network by means of the Radio Access Units. Each of the individual pieces of terminal equipment used by subscribers are assigned a directory number that remains constant regardless of where the subscriber may move within the system. This feature allows subscribers to be accessed regardless of their location within the service area of the system.

All terminal equipment is owned and operated by the using unit. The elements of the long haul communications network are owned and operated by signal units at the respective levels of command.

MSE Equipment

The operational capabilities for the items of equipment listed below are based upon the concepts inherent in the MSE architecture developed by the Army and do not necessarily reflect the capabilities of any actual items of equipment. When the actual items of equipment are procured, the capabilities described below, while available, may be implemented differently than as described.

The functional elements of the MSE system are:

1. Node centrals
2. Large extension switches
3. Small extension switches
4. Radio access units
5. Large line of sight (LOS) multichannel radio assemblages
6. Small line of sight (LOS) multichannel radio assemblages
7. Super-high frequency (SHF) radio sets
8. System control centrals (SCC)

Node centrals. One node central is located at each primary node. Each node central performs tandem switch functions for twelve trunk groups. Switching functions are processor controlled and provide adaptive route selection under changing load conditions and varying network configurations, thus increasing the survivability of the system in the event of damage or overload. In addition, the system is able to locate subscribers regardless of their location in the supported area through use of numbering plans that are independent of geographical location.

The use of a flood search technique for simultaneously locating subscribers and selecting routes accounts for the adaptability of the network. Each node central maintains directory listings only for subscribers located at supported extension nodes or RAUs. Routes are dynamically selected based on link availability and link loading. As subscribers are located, the path that was successful in locating the subscriber is the one that is used during the remainder of the exchange, establishing a virtual circuit connection.

Extension switches. Large and small extension switches provide primary user access to the communications network and are the main components of large and small extension nodes respectively. Small extension switches provide access for 30 users, while large extension switches will handle up to 150 users. Users provide their own terminal equipment and connection to the switch is by means of wire or cable. The primary wire line terminal device is the telephone. Facsimile (FAX) and microprocessor terminals may also be supported through the extension switches.

Extension switches can provide intranode switching for all local users while internode switching is provided by node centrals, or all switching tasks can be handled at the node central level. Extension switches also provide access to the communications network for combat net radios (combat net radios are usually single channel FM voice radios).

Radio Access Units (RAU). RAUs provide access to high priority mobile subscribers throughout the battlefield and each RAU can handle up to 25 mobile subscribers. Two RAUs will generally be assigned to each primary node, of which one will be collocated with the elements of the primary node while the other is located at some other location and connected to the primary node by LOS radio. The locations of the second RAUs assigned to a primary node are chosen to provide maximum accessability to users throughout the area covered by the MSE system.

As with wire line terminals, users own and operate their own equipment to gain access to the communications net through the RAUs. The user terminal is known as a Mobile Subscriber Radiotelephone Access Terminal (MSRT), and also provides a user discrete addressability within the MSE system.

Line of sight (LOS) multichannel radio assemblages. Large and small multichannel radio assemblages provide connectivity between the elements of the MSE system. Large LOS radio assemblages are located at the primary nodes and have the capability to terminate four radio links, while the small LOS radio assemblages support extension nodes and RAUs and can terminate two radio links.

Super high frequency (SHF) radio sets. These radio sets provide extension nodes the ability to separate the extension switch from the LOS radio assemblage. One SHF radio set is carried by each extension switch and the other by the small LOS radio assemblage that connects the extension switch to the primary node. These low powered radio sets have a range of five kilometers.

System control centrals (SCC). The SCC provides technical control for the MSE system. The SCC controls activations of links and node centrals, performs frequency management tasks, and provides systems analysis and displays for use by the various C-EMS elements. The SCC maintains a system database that is updated and distributed by means of continuous exchanges of data between the SCC and the node centrals that make up the system.

Each SCC will be collocated with a primary node, and there will generally be more than one SCC in a system. One of the SCCs will be designated the master SCC, while any others will function as backup, or slave, SCCs. Data base exchanges will also be conducted on a continuous basis between the master and slave SCCs.

Nodal equipment configuration. Primary nodes are the largest of the MSE system equipment configurations, consisting of one node central, three large LOS radio assemblages and one RAU. Large extension nodes are made up of one large extension switch and one small LOS radio assemblage, while small extension nodes are composed of one small extension switch and one small LOS radio assemblage. Each of the extension switches and small LOS radio assemblages in an extension node are provided with an SHF radio set. RAUs that are not collocated with a primary node have a small LOS radio assemblage assigned to them to provide connectivity to the primary node.

MSE equipment distribution. The organic signal unit at the division level is a signal battalion. The functional elements that a division signal battalion is authorized are:

1.	Node centrals	4
2.	Large extension switches	1
3.	Small extension switches	16
4.	Radio access units	9
5.	SHF radio sets	34
6.	Large LOS radio assemblages	12
7.	Small LOS radio assemblages	22
8.	System control centrals	2

The total number of user terminals that a dvision system is expected to support are:

1. Wire Line Terminals 500
2. Mobile Subscriber Radiotelephone Terminal 180

MSE Deployment

Primary nodes. Two factors must be considered when selecting locations for primary nodes. First, the primary node must be able to support extension nodes that provide users access to the system. Second, the location of the primary node must support the establishment of the backbone network's grid configuration.

The ability of a primary node to support a given extension node is dependent upon whether or not the primary node has resources available to terminate the radio link from the extension node, as well as whether or not line of sight connectivity is able to be established between the primary and extension nodes. Line of sight considerations will be most important when determining whether or not a given location will support the desired backbone network configuration.

The number of extension nodes that a primary node may support is limited by the number of trunks that are able to be terminated there. The node central and the three radio assemblages of the primary node provide the capability to terminate twelve trunks. Of the twelve trunks that the primary node can terminate, four are required to establish grid connectivity and one is required to provide RAU access. This leaves seven trunks available for extension node support.

Based on the number of trunks available at each primary node for extension node support and the number of primary nodes that can be formed from equipment available at either division or corps level, it can be seen that the primary factor affecting resource availability for a given primary is the manner in which the locations for extension nodes are selected.

Extension nodes. Extension nodes exist for the purpose of providing users access to the communications network. Thus, the primary factor to be considered when selecting locations at which to place the extension nodes is where the users are located. A second factor to be considered is that the LOS radio assemblages at the extension node and the primary node must be able to establish connectivity.

Within a division, the distribution of user owned terminal equipment requiring extension node support is as follows:

DIVISION ELEMENT	TERMINALS PER ELEMENT
Division Headquarters	90
Division Support Command	60
Division Artillery	21
Brigade Headquarters	21
Support Battalion	9
Maneuver Battalion	0
Support Company/Battery	3

As mentioned before, all terminal equipment is owned and operated by the using unit. Included as part of the operation of the piece of terminal equipment is the task of connecting it by means of wire or cable to a junction box provided by the extension switch that is part of the extension node. Each small extension switch is able to provide three junction boxes, while large extension switches are able to provide seven junction boxes.

Every extension switch, large or small, is able to provide a junction box to which using units may connect their terminal devices within the immediate vicinity of the switch assemblage. In addition, small extension switches can use cable to extend two junction boxes up to 1000 feet from the switch. Large extension switches can extend six junction boxes up to 1000 feet from the switch. This capability greatly increases the ability of an extension node to support multiple users over a large area.

Connectivity between extension nodes and primary nodes requires that the LOS radio assemblages that are part of the nodal equipment be able to establish contact. The small LOS radio assemblages that are part of the extension nodes can establish two radio links. For a small extension node, only one link is required for the node to be able to provide an acceptable grade of service. The second link of a small extension node will normally be in a standby mode to provide a backup capability in the event the first link fails and, for maximum survivablity, the backup link will ordinarily provide connectivity to a different node than the active link. For a large extension node to provide an acceptable grade of service, both links that its small LOS radio assemblage is able to provide must be active. As with the small extension node, maximum survivability is provided when the two links provide connectivity to different primary nodes.

It is very likely that the goal of selecting a location that enables an extension switch to provide access to a large number of users will conflict with the goal of selecting a location that enables connectivity to be established with two (or possibly even one) primary node. The SHF radio sets that each extension node has provide a solution to this conflict.

Both the small LOS radio assemblage and the extension switch associated with an extension node have the capability to locate their respective SHF radio set up to 500 feet from their main equipment location. As stated above, the range of the SHF radio sets is 5 kilometers. Thus, the extension switch may be separated from its radio terminal by as much as five kilometers to achieve both an acceptable grade of service and network survivability. However, a requirement for the SHF radio sets to be able to establish contact between the location of the extension switch and the location of the LOS radio assemblage must be met before the separation can be considered acceptable.

Appendix B:

Digital Terrain Database Contents

The contents of the five digital terrain databases that the Mobile Subscriber Equipment Network Design System (MSENDS) has access to are described below. For each data base, the geographic area covered by the database has been divided into cells of 10,000 square meters (100 meter squares) each. Each cell in the geographic area is assigned one of the categories from each database. The information in this appendix is taken from (18).

CROSS COUNTRY MOVEMENT database categories:
(terrain type)

1--level, open	6--light forest
2--bottomlands	7--dense forest**
3--silty, loamy	8--steep slopes**
4--sloping brushlands**	9--cantonment
5--juniper forest	

SLOPE database categories:
(percent slope)

1--0% to 2%	5--15% to 20%**
2--2% to 5%	6--20% to 25%**
3--5% to 10%	7--greater than 25%**
4--10% to 15%**	

LANDCOVER database categories:

1--other**	6--grass
2--water**	7--bare
3--forest**	8--agriculture
4--shrub	9--disturbed
5--shrub/grass	10--urban

ROADS database categories:
(point, line, and area features)

1--4 lane divided road	10--railroad bridge**
2--4 lane road	11--pipeline**
3--2 lane road	12--pipehead**
4--good dirt road	13--tank crossing
5--dirt road	14--airfield**
6--tank trail	15--airstrip**
7--minor trail	16--landing zone**
8--bridge**	17--drop zone**
9--railroad**	

ELEVATION database categories:
(meters)

1--less than 200	5--276 to 300
2--200 to 225	6--301 to 325
3--226 to 250	7--326 to 350
4--251 to 275	8--greater than 350

** indicates a category that will not satisfy proposed system constraints

Appendix C:

Actors and Attributes

Those actors whose function is to store information for the MSENDS-P system are described in the following pages. An actor's attributes, and a desription of each attribute, is given. If default values were used, these are listed after the attribute description in parenthesis. If no default values are listed, then the attribute value was initially nil.

Problem-Workspace Actor and Offspring (Figure 12a, page 59)

Actor : Problem-Workspace
Attributes : none

Actor : Domain-Workspace
Attributes : combat-force : An association list that contains the top level combat force for which the communications network is being designed, and the identification of that combat force.

signal-unit : An association list that contains the type of signal unit supporting the top level combat force and that signal unit's identification.

unit-priority-pairs : A list whose elements are 2-tuples. The first item in each tuple is the communications-priority for the unit, the second item is the unit's identification.

unassigned-units : A list of unit identifications. The units are all of equal communications-priority and have the highest priority of all units not assigned to an extension switch.

unassigned-large-extension-switches : A list of the identifications associated with instances of the large-extension-switch object. Those switches on this list are not yet supporting a unit.

unassigned-small-extension-switches : A list of the identifications associated with instances of the small-extension-switch object. Those switches on this list are not yet supporting a unit.

assigned-extension-switches : A list of the identifications associated with those switches, large and small, that have been assigned in support of a unit.

Actor : Domain-Workspace (continued)
Attributes : unassigned-node-centrals : A list of the identifications associated with instances of the node-central object. Those node centrals on this list are not associated with any extension switches, and are not providing network backbone service.

assigned-node-centrals : A list of identifications associated with those node centrals that provide access to the communications network for extension switches.

backbone-nodes : A list of the identifications of the node-centrals that are supporting extension switches and that have been incorporated into the backbone communications network.

object-pairs : This list is initially formed by either pairing off the elements of two lists or a single object and the elements of a list. After the list of pairs has been formed, the distance between the two objects is calculated and becomes the first element of a 3-tuple, with the second and third elements being the two objects for which the distance was determined.

impossible-to-assign-units : A list of the unit identifications of those units that had not been assigned to an extension switch before the capacity of the supporting signal unit was exceeded.

no-standby-trunk : A list of extension switches that have been assigned a trunk for primary node access but have not been assigned a standby trunk.

out-of-range-switches : A list of extension switches that cannot be assigned to a node-central due to being out of the planning range for any node centrals with available ports.

excess-switches : A list of extension switches that cannot be assigned to a node-central since there are more extension switches that require primary intra-node-access-trunks than there are node-centrals available.

Actor : Control-Workspace
Attributes : status : status of the top level design problem, finished or unfinished.

context : the current context in which actions are being performed. The overall network design problem is decomposed into four contexts.

knowledge-source : the knowledge source that will be providing the action within a given context.

phase : the current phase in which actions are being performed. Each of the contexts is further decomposed into phases.

number-records : Records the number of domain-workspace-records that have been created when switches are initially assigned.

Actor : Domain-Workspace-Record
Attributes : same as domain-workspace actor attributes.

Domain-Objects Actor and Offspring (Figure 11, page 57)

Actor : Domain-Objects
Attributes : scale-factor : The value by which measurements are scaled. When six digit grid coordinates are used, the scaling factor is 100 meters for each unit. For eight digit grid coordinates, the scaling factor would be 10, and four digit grid coordinates would require a scaling factor of 1000.

Actor : MSE-Equipment
Attributes : none

Actor : Units
Attributes : none

Offspring of MSE-Equipment Actor (Figure 14, page 64)

Actor : Node-Central
Attributes : distance1 : The distance in meters representing the maximum distance that a switch may be located from a node central. (25000)

distance2 : The distance in meters representing the maximum distance that may separate two extension switches that are going to be jointly assigned to a previously unassigned node-central. (50000)

inter-node-trunks : Links that provide connectivity between nodes for backbone communications network. (4)

primary-intra-node-trunks : Trunks reserved for use by extension switches or radio access units as their primary means of access to the communications network. (5)

secondary-intra-node-trunks : Trunks that are reserved for use by extension switches for standby access to the communications network. (3)

Actor : Extension-Switch
Attributes : junction-box-capacity : The large and small extension switches each have junction boxes. The capacity of the boxes is the number of terminals that may be connected per box. (30)

distance1 : Two units separated by this distance (in meters) may be able to connect to a single extension switch without any junction boxes extended from the switch. A unit located within this distance of a switch may be able to connect to the switch without the extension of a j-box. (100)

Actor : Extension-Switch (continued)
Attributes : distance2 : Two units separated by this distance (in meters) may be able to connect to a single extension switch with the switch located at one of the units and a junction box extended to the other. A unit located within this distance of a switch may be able to connect to the switch with the extension of a junction box. (300)
distance3 : Two units separated by this distance (in meters) may be able to connect to a single extension switch located midway between the two units with junction boxes extended to each unit. (600)

Actor : Large-Extension-Switch
Attributes : junction-boxes : Number of junction box access points that the switch can provide. Junction boxes provide an access point to users at a distance of up to 1000 feet from the main switch location (600 meters). (6)
terminal-capacity : The maximum number of user terminals that may be supported. (150)
primary-intra-node-trunks : Trunks used to provide the main means of access to the serving primary node. Because of the size of the large extension switch, two trunks are required to provide primary access. (2)
secondary-intra-node-trunks : Trunks that provide standby access to the communications network. (0)

Actor : Small-Extension-Switch
Attributes : junction-boxes : Number of junction box access points that the switch can provide. Junction boxes provide an access point to users at a distance of up to 1000 feet from the main switch location (600 meters). (2)
terminal-capacity : The maximum number of user terminals that may be supported. (30)
primary-intra-node-trunks : Provide the primary means of access for the switch to the communications network. (1)
secondary-intra-node-trunks : Provide standby access to the communications network. (1)

Actor : Radio-Access-Unit
Attributes : none

Actor : Shf-Radio-Set
Attributes : none

Actor : Large-Los-Radio
Attributes : trunks : The number of links that can be terminated by one radio assemblage. (4)

Actor : Small-Los-Radio
Attributes : trunks : The number of links that can be terminated by one radio assemblage. (2)

Offspring of Units Actor (Figures 15 - 16, pages 66 - 67)

Actor : Combat-Force
Attributes : none

Actor : Signal-Unit
Attributes : none

Actor : Corps
Attributes : composed-of : a list of the types of subordinate
    units that are found in a corps.
        (corps-headquarters
         corps-support-command
         group-headquarters battalion company
         division)

Actor : Corps-Headquarters
Attributes : communications-priority : a number representing how
    important it is that a unit be provided
    communications support. (50)
  terminals : the number of devices that will be
    connected by wire to the communications
    system access point by a unit. (120)
  location : a list of two three-digit numbers that
    make up the six digit grid coordinate of the
    location of the unit.

Actor : Group-Headquarters
Attributes : communications-priority : a number representing how
    important it is that a unit be provided
    communications support. (40)
  terminals : the number of devices that will be
    connected by wire to the communications
    system access point by a unit. (30)
  location : a list of two three-digit numbers that
    make up the six digit grid coordinate of the
    location of the unit.

Actor : Corps-Support-Command
Attributes : communications-priority : a number representing how
    important it is that a unit be provided
    communications support. (30)
  terminals : the number of devices that will be
    connected by wire to the communications
    system access point by a unit. (90)
  location : a list of two three-digit numbers that
    make up the six digit grid coordinate of the
    location of the unit.

Actor : Division
Attributes : composed-of : a list of the subordinate units in the division that require communications support from the MSE system.
(division-headquarters
brigade-headquarters
division-support-command
battalion
company)

Actor : Division-Headquarters
Attributes : communications-priority : a number representing how important it is that a unit be provided communications support. (50)
terminals : the number of devices that will be connected by wire to the communications system access point by a unit. (90)
location : a list of two three-digit numbers that make up the six digit grid coordinate of the location of the unit.

Actor : Brigade-Headquarters
Attributes : communications-priority : a number representing how important it is that a unit be provided communications support. (40)
terminals : the number of devices that will be connected by wire to the communications system access point by a unit. (21)
location : a list of two three-digit numbers that make up the six digit grid coordinate of the location of the unit.

Actor : Division-Support-Command
Attributes : communications-priority : a number representing how important it is that a unit be provided communications support. (30)
terminals : the number of devices that will be connected by wire to the communications system access point by a unit. (60)
location : a list of two three-digit numbers that make up the six digit grid coordinate of the location of the unit.

Actor : Battalion
Attributes : communications-priority : a number representing how important it is that a unit be provided communications support. (20)
terminals : the number of devices that will be connected by wire to the communications system access point by a unit. (9)
location : a list of two three-digit numbers that make up the six digit grid coordinate of the location of the unit.

```
Actor : Company
Attributes : communications-priority : a number representing how
                important it is that a unit be provided
                communications support. (10)
             terminals : the number of devices that will be
                connected by wire to the communications
                system access point by a unit. (3)
             location : a list of two three-digit numbers that
                make up the six digit grid coordinate of the
                location of the unit.


Actor : Division-Signal-Battalion
Attributes : equipment : a list of the major items of equipment
                that a division signal battalion uses in
                making a communications system and the number
                of pieces of the individual items that are
                expected to be found in the signal unit.
                    ((node-central              4)
                     (large-extension-switch    4)
                     (small-extension-switch   16)
                     (radio-access-unit         9)
                     (shf-radio-set            34)
                     (large-los-radio          12)
                     (small-los-radio          22))

Actor : Corps-Signal-Brigade
Attributes : composed-of : a corps signal brigade is composed of
                area signal battalions.  The number of area
                signal battalions depends upon the number of
                divisions the corps is composed of.
                    (corps-area-signal-battalion
                     division-signal-battalion)

Actor : Corps-Area-Signal-Battalion
Attributes : equipment : a list of the major items of equipment
                that a corps area signal battalion uses to
                make a communications system and the number
                of pieces of the individual items that are
                expected to be found in the signal unit.
                    ((node-central              9)
                     (large-extension-switch    1)
                     (small-extension-switch   36)
                     (radio-access-unit        19)
                     (shf-radio-set            74)
                     (large-los-radio          27)
                     (small-los-radio          47))
```

Appendix D:

Production Rules

The rules used by the Mobile Subscriber Equipment Network Design System prototype (MSENDS-P) knowledge-source type actors Priority-Assignment and Nodal-Assignment are presented in the following sections. Within each set of rules, the rules are evaluated in the order they are listed. As soon as a set of conditions is met, the indicated action is performed and no further conditions are evaluated. Thus, the rules presented generally progress from the most specific to the least specific conditions.

Priority-Assignment Actor Rules

The following sets of rules are used by the Priority-Assignment actor to assign an extension switch to a unit. Extension switches may be assigned to a single unit or to a pair of units. A unit may also be assigned to an extension switch previously assigned to a unit with a higher communications priority that has sufficient capacity to support additional terminals.

Paired Object Rules. Presented first are rules applied following the pairing of units with assigned extension switches and other units. The distance between the two objects of each pair has been calculated.

```
     IF    the separation is less than 100 meters
                       and
           both objects in the pair are units
                       and
           there is an unassigned switch with the capacity to
           handle the combined terminal load
     THEN  assign a switch to the two units;

else IF    the separation is less than 100 meters
                       and
           one object in the pair is a switch
                       and
           that switch has sufficient capacity to handle the
           additional terminals of the unit
     THEN  the unit is added to the switch;

else IF    the separation is less than 300 meters
                       and
           both items in the pair are units
                       and
           there is an unassigned switch with the capacity to
           handle the combined terminal load
     THEN  the switch is collocated with one of the units and a
           junction box is extended from the switch to the
           other unit;

else IF    the separation is less than 300 meters
                       and
           one object in the pair is a switch
                       and
           that switch has sufficient capacity to handle the
           additional terminals of the unit and an available
           junction box
     THEN  a junction box is extended from the switch to
           the new unit;

else IF    the separation is greater than or equal to 300 meters
                        and
           the separation is less than or equal to 600 meters
                        and
           both items in the pair are units
                        and
           there is an unassigned switch with the capacity to
           handle the combined terminal load
     THEN  the extension switch is located midway between the
           two units and junction boxes are extended from the
           switch to each unit;

else the separation is greater than 600 meters and the unit or
     units must be dealt with individually.
```

Single Unit Rules. The rules presented next are used to assign a single unit to an extension switch. Single unit assignment rules are used when a unit is not located near an already assigned extension switch or if the unit has more terminals that require support than any single available extension switch can provide.

```
     IF   the number of terminals the unit possesses is less
          than the capacity of a small extension switch
                       and
          there is a small extension switch available
     THEN assign a small extension switch to the unit;

else IF   the number of terminals the unit possesses is less
          than the capacity of a large extension switch
                       and
          there is a large extension switch available
     THEN assign a large extension switch to the unit;

else IF   there are large extension switches available
     THEN partially assign the unit to a large switch;

else partially assign the unit to a small switch.
```

Nodal-Assignment Actor Rules

Two sets of rules are used by the Nodal-Assignment actor. One set is used while assigning extension switches to node-centrals and selecting node-central locations. The other set is used to create the backbone communications network. Each node central is allocated five communications ports for connections to extension switches and four ports for connections to other node centrals to form the backbone network.

Assigning Switches to Node Centrals. The following set of rules is applied following the calculation of the distance between each extension switch and all assigned node centrals. If any unassigned node centrals are available, the distances separating extension switches are also calculated.

```
     IF    the separation distance is less than 25 kilometers
                     and
           one of the items in the pair is a node central
                     and
           the other item is a small extension switch
                     and
           the node central has an available port
     THEN  the switch is connected to the node central
                     and
           the position of the node central is changed to halfway
           between its previous position and the position of
           the assigned switch;

else IF    the separation distance is less than 25 kilometers
                     and
           one of the items in the pair is a node central
                     and
           the other item (which must be a large extension switch)
           is not already connected to the node central
                     and
           the node central has an available port
     THEN  the switch is connected to the node central
                     and
           the position of the node central is changed to halfway
           between its previous position and the position of the
           assigned switch;

else IF    the distance is less than 50 kilometers
                     and
           both items in the pair are extension switches
                     and
           there is an unassigned node central
     THEN  assign the two switches to a node central
                     and
           locate the node central midway between the two
           extension switches;

else IF    the distance is less than 50 kilometers
     THEN  ignore the current pair and select the next closest
           pair;

else the remaining extension switches are outside the planning
     radius of the line of sight radios.
```

Backbone Communications Network formation. The final set of rules is used to connect node centrals to form a backbone communications network. The distance between each possible pair of node central locations has been calculated.

```
     IF   the separation distance is less than 25 kilometers
                    and
          both node centrals have an available port
                    and
          no connection between the two already exists
     THEN connect the two node centrals;

else IF   the separation distance is less than 25 kilometers
     THEN ignore the current pair and find the next
          closest pair;

else the line of sight planning radius has been exceeded.
```

Bibliography

1. Bonfatti, F. and others. "Structure and Use of a Geographic Data Base for Mobile Radio Propagation Prediction," IEEE International Conference on Communications, Vol. 1. Paper A2.8, 77-81. IEEE Publishing Services, New York, 1983.

2. Brachman, Ronald J. and others. "What are Expert Systems?", Building Expert Systems, edited by Frederick Hayes-Roth and others. Reading, Massachusetts: Addison-Wesley Publishing Company, Inc., 1983.

3. Brown, David C. and B. Chandrasekaran. "An Approach to Expert Systems for Mechanical Design," 1983 Trends & Applications: Automating Intelligent Behavior-Applications & Frontiers. 173-180. IEEE Publishing Services, New York, 1983.

4. Chester, Daniel. Elements of Knowledge Based Expert Systems. Grant AFOSR-80-0190. Department of Computer and Information Science, University of Delaware, Newark, Delaware, March 1982 (AD-A136 093).

5. Damosso, Eraldo and Bernardo Lingua. "A Computer Prediction Technique for Land Mobile Propagation in VHF and UHF Bands," IEEE International Conference on Communications, Vol. 1. Paper A2.4, 59-63. IEEE Publishing Services, New York, 1983.

6. Department of the Army. Dictionary of United States Army Terms. AR 310-25. Washington, D. C.: HQ DA, 1 June 1979.

7. -----. Communications-Electronics Operations, Orders, Records, and Reports. FM 24-16. Washington, D. C.: HQ DA, 7 April 1978.

8. -----. Communications-Electronics Management System. FM 24-22. Washington, D. C.: HQ DA, 30 June 1977.

9. -----. Operations. FM 100-5. Washington, D. C.: HQ DA, 29 April 1977.

10. -----. Combat Communications within the Division. FM 11-50. Washington, D. C.: HQ DA, 31 March 1977.

11. -----. Combat Communications. FM 24-1. Washington, D. C.: HQ DA, 30 September 1976.

12. -----. Map Reading. FM 21-26. Washington, D. C.: HQ DA, 20 January 1969.

13. Dixon, J. R. and others. "An Architecture for Application of Artificial Intelligence to Design," 21st Design Automation Conference Proceedings Paper A40.2, 634-640. IEEE Publishing Services, New York, 1984.

14. Dunlap, Samuel O. Terrain Masking Analysis for White Sands Missle Range East Center 50 and West Center 50. Technical Report RE-81-25. U. S. Army Missle Command, Redstone Arsenal, Alabama, July 1981 (AD-A105 806).

15. Foderaro, John K. and others. The FRANZ LISP Manual. The Regents of the University of California, Berkeley, California, June 1983.

16. Gerla, Mario and Leonard Kleinrock. "On the Topological Design of Distributed Computer Networks," IEEE Transactions on Communications, Com-25: 48-60, (January 1977).

17. Giasson, MAJ (P) Charles B. "Army Tactical Frequency Engineering System," Army Communicator, 9: 18-23 (Summer 1984).

18. Goran, William D. and others. Fort Hood Geographic Information System: Pilot System Development and User Instructions. Technical Report N-154. United States Army Corps of Engineers Construction Engineering Research Laboratory, Champaign, Illinois, May 1983 (AD-A130 618).

19. Hayes-Roth, Barbara. "A Blackboard Architecture for Control," Artificial Intelligence, 26: 251-321 (1985).

20. Hayes-Roth, Frederick and others. "An Overview of Expert Systems," Building Expert Systems, edited by Frederick Hayes-Roth and others. Reading, Massachusetts: Addison-Wesley Publishing Company, Inc., 1983.

21. Joy, William. "An Introduction to the C Shell," UNIX Programmer's Manual (Seventh Edition). Computer Science Division, Department of Electrical Engineering and Computer Science, University of California, Berkeley, California, November 1980.

22. Kelley, William E. and LTC Louis S. Martin. "Mobile Subscriber Equipment: A New Acquisition Approach," Army Communicator, 9: 17-18 (Spring 1984).

23. Kleinrock, Leonard. "On Communications and Networks", IEEE Transactions on Computers, C-25: 1326-1335 (December 1976).

24. Loew, K. and R. W. Lorenz. "Determination of Service Areas for Mobile Communication with a Topographical Data Base," IEEE International Conference on Communications, Vol. 1. Paper A2.3, 54-58. IEEE Publishing Services, New York, 1983.

25. McArthur, Dave and Philip Klahr. The ROSS Language Manual. Rand Note N-1854-AF. The Rand Corporation, Santa Monica, California, September 1982.

26. McGregor, Patrick V. and Diana Shen. "Network Design: An Algorithm for the Access Facility Location Problem," IEEE Transactions on Communications, Com-25: 61-73 (January 1977).

27. Meyer, S. and J. Pihan. "Coverage Prediction for Rural Telephony Systems," IEEE International Conference on Communications, Vol. 1. Paper A2.7, 72-76. IEEE Publishing Services, New York, 1983.

28. Niimi, Hideki and others. "Computer Aided Analysis of Propagation Characteristics Using Topographical Mesh-Data Basis," IEEE International Conference on Communications, Vol. 1. Paper A2.2, 49-53. IEEE Publishing Services, New York, 1983.

29. Rich, Elaine. Artificial Intelligence. New York: McGraw-Hill Book Company, 1983.

30. Rychener, Michael D. Expert Systems for Engineering Design: Problem Components, Techniques, & Prototypes. Design Research Center & Robotics Institute, Carnegie-Mellon University, Pittsburgh, Pennsylvania, 26 March 1984.

31. Schaum, Don and others. "MSE: Mobile Subscriber Equipment," Army Communicator, 9: 6-22 (Fall 1984).

32. Schneider, G. Michael and Mary N. Zastrow. "An Algorithm for the Design of Multilevel Concentrator Networks," Computer Networks, 6: 1-11 (1982).

33. Simon, Herbert A. "The Structure of Ill Structured Problems," Artificial Intelligence, 4: 181-201 (1973).

34. Stefik, Mark and others. "Basic Concepts for Building Expert Systems," Building Expert Systems, edited by Frederick Hayes-Roth and others. Reading, Massachusetts: Addison-Wesley Publishing Company, Inc., 1983.

35. Thompson, CPT Michael R. and Robert M. Socher. Digital Terrain Analysis Station (DTAS). ETL-R040. U. S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia, 28 August 1982 (AD-A119 298).

36. United States Army Signal Center and Fort Gordon. Draft Operational and Organizational Plan for Mobile Subscriber Equipment (MSE) System. Working Papers. Fort Gordon, Georgia: USASC&FG, November 1984.

37. -----. Tactical Automatic Circuit Switching, AN/TTC-39. FC 24-27-1. Fort Gordon, Georgia: USASC&FG, 1 January 1984.

38. -----. Communications-Electronics Management System(C-EMS). Information Sheet BOAC/G09-LP1 4C-0A25/E69-LP1-IS(1). Fort Gordon, Georgia: USASC&FG, May 1979.

39. United States Army Signal School. Operations and Training Handbook. ST 11-140. Fort Gordon, Georgia: USASIGS, 1 May 1976.

40. Whitteker, James H. "Propagation Prediction From a Topographic Data Base," IEEE International Conference on Communications, Vol. 1. Paper A2.1, 44-48. IEEE Publishing Services, New York, 1983.

41. Winston, Patrick Henry. Artificial Intelligence (Second Edition). Reading, Massachusetts: Addison-Wesley Publishing Company, 1984.

Vita

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This ~~project~~ designed a knowledge based system that will assist tactical communications systems planners design tactical communications networks. The system was developed to be used with a new generation of United States Army tactical communications equipment, the Mobile Subscriber Equipment (MSE) System, and was named the Mobile Subscriber Equipment Network Design System (MSENDS).

MSENDS is designed to use terrain knowledge available from digital terrain databases, and knowledge specific to the MSE system to perform the network design process. The heuristic network design method of clustering is used to develop an initial terrain independent network design. The initial design is then evaluated using terrain knowledge and MSE specific knowledge for constraint satisfaction. Network redesign strategies are invoked as unsatisfied constraints are identified. The evaluation and redesign of the network is performed iteratively until a satisfactory design is achieved.

A prototype of MSENDS was implemented to evaluate the proposed design. A blackboard architecture that enabled non-chronological backtracking to be used was implemented. The prototype does not use terrain knowledge in its design or redesign operations; only MSE specific knowledge is used by the prototype.

It was found that the use of the design, evaluate, redesign architecture, coupled with MSE specific knowledge was able to design a network with a lower cost than was produced by a system employing no domain specific knowledge. These results indicate that the proposed system may be useful in the design of tactical communications networks.

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